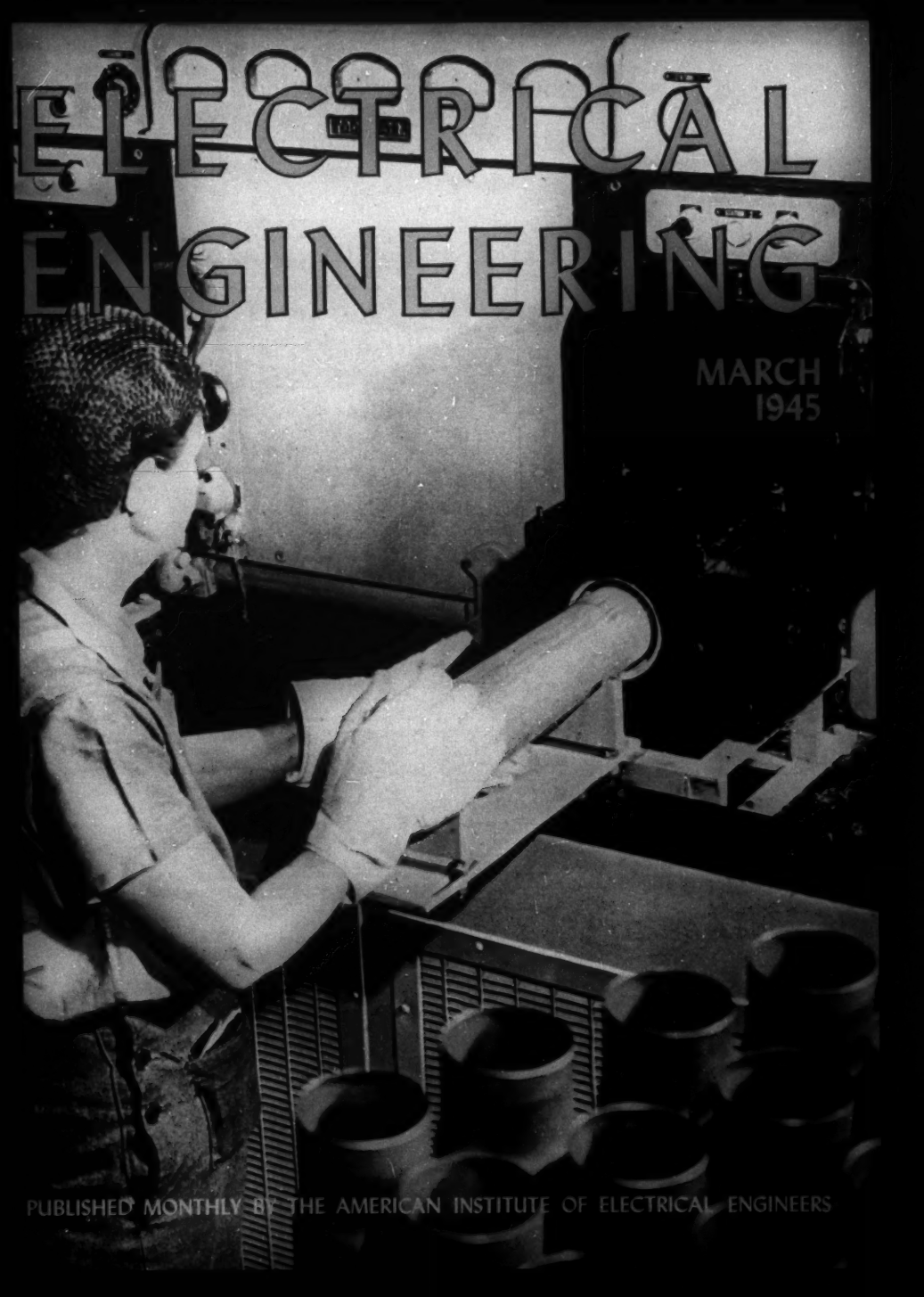
ELECTRICAL ENGINEERING

MARCH
1945



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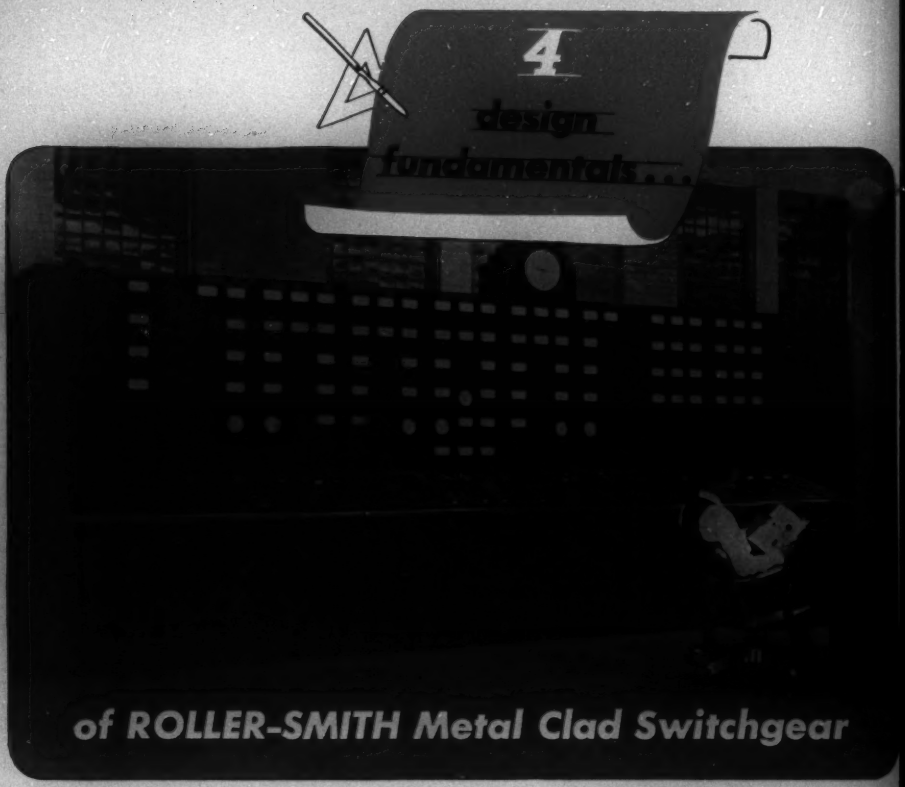

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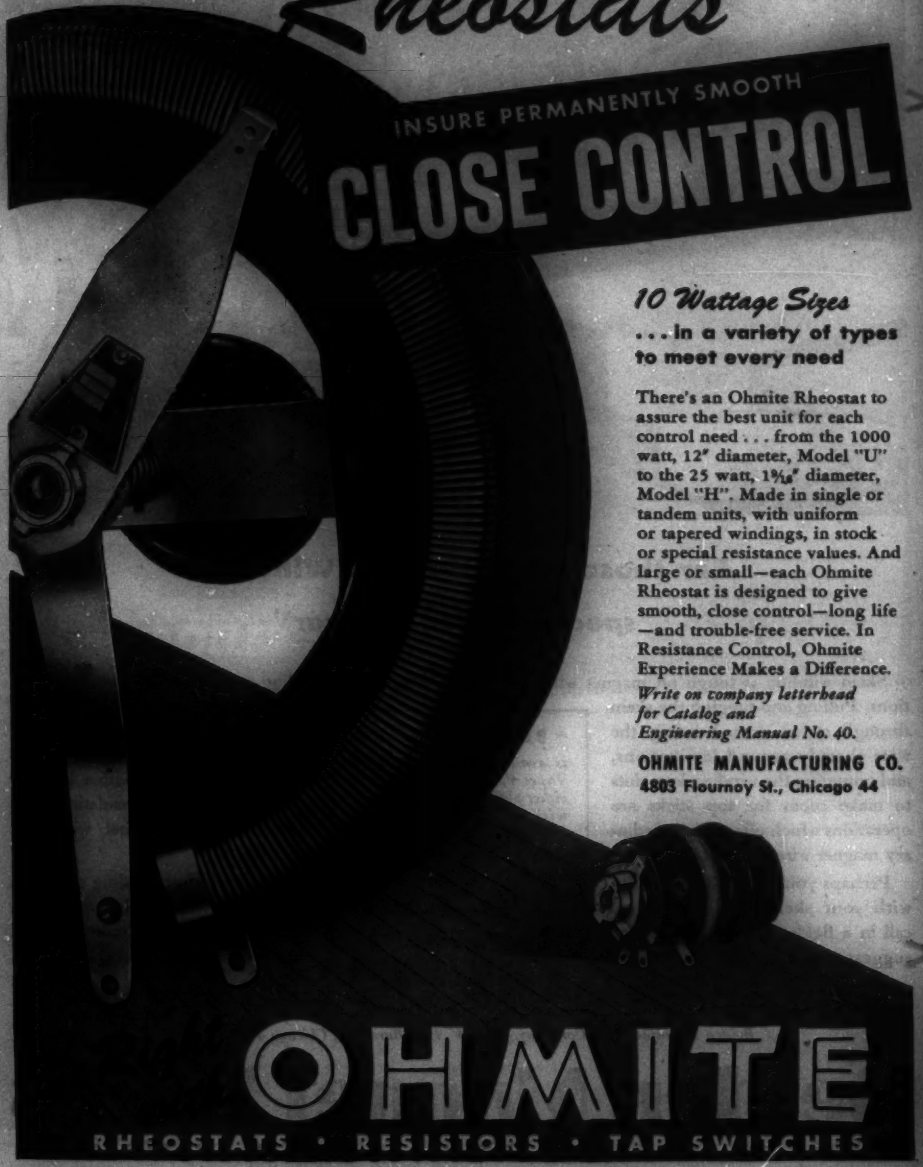

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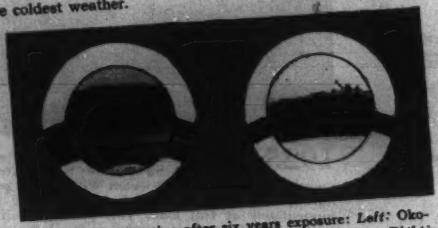

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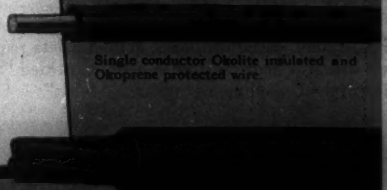

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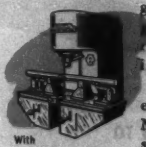

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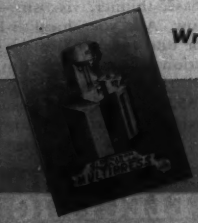

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1945

The Cover: High-frequency induction heating anneals the mouths of large steel cartridge cases to permit crimping onto shot or shell and to prevent splitting during use.

Photo courtesy The Ohio Crankshaft Company

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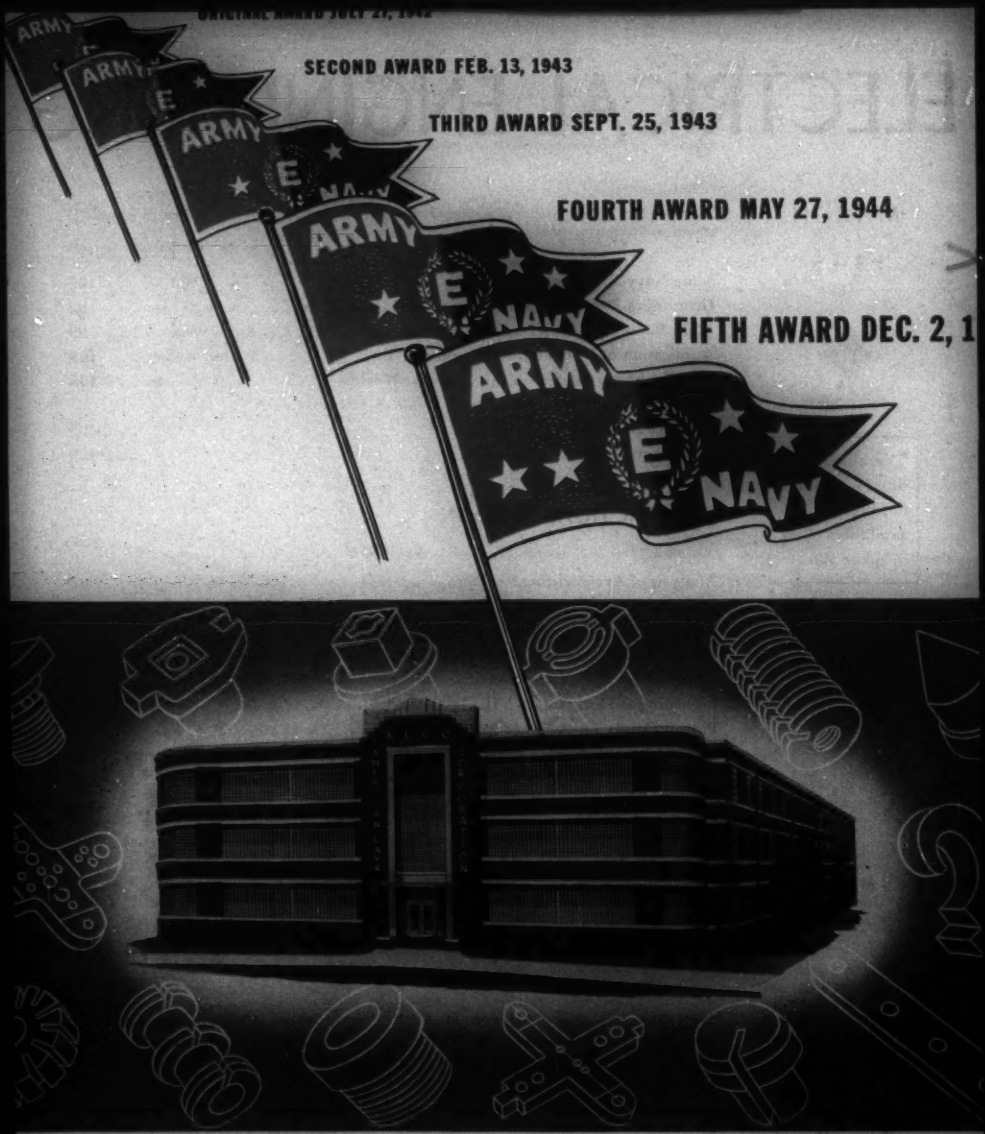

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ELECTRICAL ENGINEERING
VOLUME 64, NUMBER 3 MARCH 1945

Some Navy Electronics Problems and a Proposal for a Radar Patent Pool

J. B. DOW

A proposal that $25,000,000 a year be set aside for a peacetime electronic research and development program for the Navy, a statement of the necessity of more thoroughgoing and extensive standardization of component parts, and a suggestion for a radar patent pool to solve the postwar radar problem are the high lights of this article.

ELECTRONICS is playing a leading role in the present great war in which substantially the entire world is engaged. Because it is the newest of the arts used in warfare on a great scale, because it has become the very heart of so many tools and weapons, and because its field of usefulness and the art itself are developing so fast, the outcome of the present war very well may be decided in favor of the nations which maintain the greatest lead in this field.

The Navy, the Army, and the Nation are depending upon the men and women of science and industry to maintain the lead which the United Nations now hold. From their minds and hands have come equipments and devices so important and so widely used that they take second place only to the personnel of our Armed Forces who utilize them; without these tools our forces would be at a hopeless disadvantage against enemies such as we are dealing with today.

The Navy always has recognized the importance of radio communication in the operation of ships and aircraft and for many years prior to the present conflict had been aware of the equally or more important part which other types of electronic equipment might play in a future war. The Navy continuously has sought equipment, components, and materials just a little better than industry thought at the time could be produced, and, when these materials were developed or produced, it almost invariably tightened its specifications or otherwise asked for more the next time. As a result of the co-operation, ingenuity, skill, and resources of science and industry, Navy communication equipment was well designed for the big job ahead at the time of our entrance into the war.

A long period of research and development by the Naval Research Laboratory with the assistance of the tube laboratories, and, later, the leading equipment manufacturers, had produced some very satisfactory types of radar, and by December 7, 1941, these were coming off the production lines in considerable numbers.

RESEARCH RELATED TO FUNDS

Much of what is done in research and development depends upon funds available for the purpose. Prior to the Navy fiscal year 1942 there was made available to the Naval Research Laboratory for electronic research and development an average annual sum of approximately $300,000 to cover the salaries of scientific personnel and project material. Funds for labor and the overhead connected with the laboratory were provided in addition to this. In 1942 this figure increased to approximately $600,000. For the fiscal year 1945 a figure of approximately $8,855,000 will have been reached.

While the Navy depends upon its own research and development facilities for much of this work—particularly where developments require the highest degree of security, or where by their nature, they are of little interest to commercial laboratories—at the same time much of the work is contracted to commercial electronic research and engineering organizations. The funds being spent during the fiscal year 1945 on such commercial contracts for research and development work will amount to approximately $38,000,000, exclusive of an estimated $25,000,000 being expended for development work under production contracts. These latter two figures total $63,000,000. The corresponding figure prior to the fiscal year 1942 was approximately $3,800,000.

Since the establishment of the Office of Scientific Research and Development, the Navy has drawn heavily upon the directly administered or contracted laboratory services of that office. In terms of dollars, the very substantial contribution of these laboratories to Navy research and development, probably would be at least equal to the $8,855,000 previously indicated for the Naval Research Laboratory with certain overhead and labor similarly not included. In the fiscal year 1945 a total of approximately $80,000,000 will have been contributed to Navy research and development in the electronic fields of radio, radar, and sonar, in comparison with a corresponding figure of roughly $3,800,000 prior to 1942.

The spread between these wartime and peacetime figures is so great that, even with full recognition of the fact that a war greatly accelerates the demand for research and development, the only sound conclusion which can be drawn is that we do not do enough such work in peacetime to prepare properly for war. When we emerge from the present world catastrophe, it is to be hoped that the need for an adequate peacetime research and development program will not be forgotten and that a minimum of $25,000,000 per year can be made available to the Navy for this work in the fields of radio, radar, and sonar.

A forward-looking, well-organized, and directed research program of adequate scope is admittedly costly, but it is nowhere near so costly in dollars and lives as a research program undertaken too late or after war begins, because following research comes the long design, development, and testing period necessary before new discoveries and modifications can be translated into terms of equipments installed and ready to use.

Intense wartime research, such as has been conducted by the Navy through the Naval Research Laboratory, the National Defense Research Committee, and a

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Essential substance of an address delivered at a joint session of AIEE and Institute of Radio Engineers, January 24, 1945, during the AIEE winter technical meeting, New York, N. Y.

Captain J. B. Dow is director, electronics division, Bureau of Ships, United States Navy, Washington, D. C.

great many commercial agencies, has advanced the art of electronics by many years. The bulk of electronic weapons which are now in large-scale production and use probably would not have been available in their present forms for another ten years without that intense research. However, many would have been available before December 7, 1941, had the importance of research and development been recognized to the extent which this war of science has taught us, and had funds been available to carry out vigorously a well-planned program.

To say that any nation is ahead of any other in a scientific art is likely to be misleading unless the comparison is based upon identical needs. Except in the case of submarines, Germany no longer has a navy of any considerable importance. Japan has one of considerable size, but it is not required to operate 8,000 miles from its prime supply sources and repair bases. From such observations as we have been able to make, it is safe to state that, from the Navy point of view, American science and industry have met our needs as well as the Germans have met theirs. We have good reason to believe these needs of our Navy have been considerably better met than the corresponding ones of Japan.

At the end of December 1941 the Navy comprised a total of 2,082 vessels and landing craft in each of which at least one transmitter and two receivers were installed. As of December 1, 1944, this figure had risen as a result of the shipbuilding program to 37,981. A large carrier has installed in it 101 complete equipments. A battleship has 78 such equipments. A small motor torpedo boat has seven. Certain of the smaller types of landing craft have as many as 13 complete equipments; others have as few as three. It is estimated that since December 7, 1941, some 300,000 complete equipments, each comprising two to 15 major units of equipment, have been installed in these 38,000 vessels and landing craft. Some idea of the complexity of these equipments can be gained when I say that they vary in cost from a few hundred dollars for a simple receiver to $250,000 for the most complex item. This installation task, accomplished by the Navy Yards, private shipbuilders, repair shipyards and other groups is one of the outstanding large-scale accomplishments of the war.

The program covering aircraft electronic equipment is equally worthy of note and in dollar value is almost identical with the ship program. In December 1941 the Navy had 5,200 service airplanes. By January 1, 1945, this figure had grown to be in excess of 38,000. These had to be equipped with transmitters, receivers, altimeters, direction finders, homing devices, radars, and other related equipment, varying from a minimum of three complete equipments for the smallest planes to ten in the case of the largest. The other programs involving equipment for the Marine Corps and shore and advanced base activities also are by no means small ones.

Delivery of electronic equipment under the administration of the electronics division, Bureau of Ships, has grown in dollar value from approximately $4,000,000 per month in 1941 to considerably over $100,000,000 per month in 1944. During the calendar year 1944 there was delivered to the Navy in excess of $1,300,000,000 worth of radio, radar, and sonar equipment, exclusive of a very large amount of equipment purchased directly from the Army.

CLIMATIC CONDITIONS SEVERE

The successful prosecution of the Navy's electronics program is contingent among other factors, upon the expeditious solution of many component-part problems. Navy electronic equipment is being used at present in every theater of war, where climatic and other conditions encountered are so severe that the establishment of simulating laboratory tests is an extremely difficult problem. A few of the general severe conditions are as follows:

High temperature combined with high humidity is encountered in countries such as Malaya, Burma, the East Indies, and the Philippines where the rainfall is constantly heavy on most days during the wet season. The air temperature may rise by day to 40 degrees centigrade and normally falls to about 25 degrees centigrade at night, but is never less than 20 degrees centigrade. Consequently, the relative humidity is very high and frequently reaches saturation for considerable periods.

High-temperature and low-humidity conditions prevail in many regions; air temperatures as high as 58 degrees centigrade occur during the day, and a drop to freezing occurs at night. The relative humidity in these regions may be as low as five per cent.

Subzero temperatures are encountered in Siberia, Alaska, northeastern Europe, and the northern parts of Canada. Temperatures as low as −40 degrees centigrade frequently are experienced. Temperatures of −55 degrees centigrade are relatively common, and −70 degrees centigrade may occur in isolated regions. Equipment generally is not required by specifications to work below −40 degrees centigrade, but must not suffer any permanent ill effects through transport or storage at the lowest temperature met.

Components may be exposed to an air pressure of 120 millimeters of mercury at an altitude of 42,000 feet. The rate of change of air pressure may be as high as ten millimeters of mercury per second. It should be remembered that equipment not designed for operation when air-borne may have to be transported by air freight at high altitudes.

Air temperature at 42,000 feet is reasonably constant at about −55 degrees centigrade. The rate of temperature change experienced by descending aircraft may be as high as five degrees centigrade per minute, but the actual rate of temperature change of apparatus will be lower, possibly two to three degrees centigrade per minute.

Equipment is liable to suffer prolonged exposure to salt-laden atmosphere and spray from sea water.

Dust may be encountered as a cloud created a few feet above ground level by moving vehicles or as a dust storm created by strong winds which drive the particles to considerable heights and in all directions. The dust particles may be abrasive or hygroscopic.

In an atmosphere near saturation and other favorable tropical conditions, fungus will start to form within a few days. Many destructive insects also are encountered in jungle regions. The effects of fungi and insects are very serious and call for much additional work on "tropicalization" of components and equipment.

All equipment must withstand without serious reduction in performance or reliability severe mechanical vibration, shocks, and rough handling.

The experience gained in this war has shown that a high percentage of those components designed for domestic commercial service cannot withstand the extremely severe climatic and other conditions to which they are exposed, either out of doors or under inadequate shelter during shipment, storage, and operation, in forward areas. In addition, many refinements and advances in radio, radar, and sonar design during the present war have imposed heavier demands upon the component designers and manufacturers of smaller, lighter, and more dependable types of components the need for which was not entirely realized even a few years ago. In many instances improvements in the designs of components have not kept pace with equipment advances, consequently, the problem of improving the usefulness, dependability, and ease of maintenance of equipment in the field is contingent largely upon improving the quality and performance of various necessary components, rather than upon further refinements in the basic equipment designs.

Improvement of the dependability of components is contingent largely upon more thoroughgoing and extensive qualification testing of components themselves. In many instances misapplication of components with attendant high failure within equipment can be traced directly to the fact that the limitations of the component with respect to electrical ratings, temperature, vibration, pressure, and so on, had never been accurately established for the guidance of the equipment-design engineer. In this connection, the Navy is establishing at the Naval Research Laboratory a $1,000,000 component-testing laboratory supplied with the necessary measuring apparatus and technical personnel to pursue an active and continuing program for the improvement of components required in radio, radar, and sonar equipments. It is intended that

this activity shall be maintained in peacetime on a large scale in order that the types of components suitable for Naval usage can be ascertained and made the subject of continuous improvement. The present qualification testing of components, under joint Army–Navy standard specifications, is being done on an appreciable scale at this laboratory and will increase as additional types of components are covered by approved *JAN* specifications.

The actual work of joint standardization of components has been carried on for over 2½ years by the Bureau of Ships and the Signal Corps, in collaboration with the American Standards Association, the War Production Board and representatives of industry, and has resulted in about 40 published standard specifications with many more to follow in the future.

To facilitate better the work of component-part standardization the Army–Navy Electronics Standards Agency, now quite generally known by its brief title *ANESA*, was established in December 1943 and was given the responsibility and authority for co-ordinating electronic-equipment component specifications to be used by both services. After drafting, the co-ordinated specifications are processed independently by the Bureau of Ships and the Signal Corps through approved channels, and, after industry and WPB have offered comments for consideration, a final approved draft is submitted to the Joint Army and Navy Committee on Specifications for approval as a *JAN* specification.

Following issuance of the approved *JAN* specification, the laboratory facilities of the Signal Corps and of the Navy are pooled to carry out the qualification testing of components and materials submitted by prospective suppliers. Test reports resulting from qualification tests are reviewed by both services, regardless of which service laboratory conducted the tests. Following review of the test reports, independent action is taken by each service to establish listings of approved manufacturers of standard components and materials. Action at present is being taken to work out a procedure by which joint Army–Navy approval certificates can be issued.

It is believed that the following benefits to the Navy would result directly from standardization:

1. Replacement components in Navy yards and depots and in the field are more readily identified and, therefore, more readily usable among various types of Navy electronic equipments since the standard components can be identified by standard markings, nomenclature, color coding, and so forth. In this connection, a very major maintenance problem exists in the Navy at the present time, because the present nonstandardized systems of marking components do not permit relatively inexperienced personnel to identify usable substitutes or often even identical items supplied by the many equipment manufacturers.

2. The work load imposed on field maintenance personnel, especially those inexperienced in maintaining equipment is made less burdensome by virtue of the relatively smaller number of noninterchangeable components of each particular type which must be stocked, properly packed, housed, and correlated with the proper Navy electronic equipment.

3. The expanded use of standard components will minimize the vast numbers of components with respect to types, sizes, and ratings, which must be dealt with in regard to improvement, testing, inspection, procurement, stock upkeep, issue, and cataloging, and hence will reduce the man-hours required for preparing necessary drawings, specifications, stock catalog numbers, and other clerical work.

4. The co-ordination of production among the various plants of equipment and component manufacturers and control and scheduling of component deliveries to equipment manufacturers can be accomplished on a far better basis through the availability of standardized and co-ordinated components. During the past three years one of the most difficult problems has been that of co-ordinating the production of Navy electronics equipment among the many equipment prime contractors to make maximum use of facilities for the production of components, the availability of which too often has limited and seriously delayed the production of equipment. The magnitude of this problem can be appreciated when one realizes that some thousand different plants and laboratories have been working under Army or Navy contracts in supplying electronic components and equipment. Component standardization will go a long way toward the solution of problems resulting from this cause.

One difficulty in the standardization of components has been the disinclination of many engineers, both in the Government and in industry, to become involved in the tedious, detailed, and relatively uninteresting work associated with the preparation of standards, with the result that a heavy work load has been imposed on a restricted group. The responsibility for component standardization must be assumed by a greater number of engineers who have a combined knowledge of the needs of industry and the armed services and of standardizing procedures.

Another difficulty experienced in that phase of component standardization having to do with the establishment of performance requirements is the tendency on the part of a relatively small portion of industry to question and discount heavily the necessity for some of the stringent and detailed requirements stipulated by the armed services. The services are not in every case 100 per cent correct in asking for certain tight and detailed requirements. However, by virtue of living with and having the responsibility for correcting failures in the field under conditions in the field, the armed services do have knowledge of the need for special performance requirements.

STANDARDS EFFECTIVENESS REDUCED

In the past and even at present the advantages of standard *JAN* specifications are being vitiated by requests for waivers from the required tests. Such waivers in whatever form granted, and if allowed to increase in number, rapidly reduce the value of standard specifications to an ineffectual level. The effectiveness of any good standard is contingent largely upon all interested activities voluntarily making every effort toward its adoption and application as a desirable instrument to implement mass production and simplify maintenance problems. Requests for waivers should be made only in cases of the highest urgency.

The production of dependable and easily maintained equipments with the least component complexity is contingent greatly upon the early selection and application by the equipment-design engineer of standard approved items for the various required components during the conception, research, and development phases. Research personnel and development engineers working on the early stages of equipment development are far too prone to use non standard components in their early experiments, consequently, far too often the resulting mechanical and electrical problems left to the final design engineers are so formidable that many nonstandard components are left in the equipment as it is finally delivered, and thus the great benefits of component standardization are lost.

While the prime effort of component standardization must be directed toward the problems of immediate urgency in advancing the present and future activities of this global war, it is hoped that the component standardization achieved during the war will not be shelved in the postwar period but will be expanded and improved. The reorderings, delays, waste of material, waste of shipping and storage space, excessive purchases of spare parts, added costs, and many other undesirable conditions arising from the use of nonstandardized items, must be vastly reduced. Taken collectively, these undesirable conditions probably already have cost the Navy $100,000,000 in this war. What has been accomplished in standardization under war conditions will be lost again in the years of peace to follow unless industry continues to understand and give full support to the solution of the problems of the services.

Of considerable importance also is the postwar radar patent situation. This new and important art was born only a few years preceding this war, and probably 95 per cent of the so-called radar inventions upon which patent applications have been filed or are in process have been made since January 1, 1941. Because of

the restrictions which have been placed on the dissemination of information concerning radar developments, little information is available concerning the number, nature, and scope of patent applications on file and in process, except to a relatively few officers of the Government. A large number of inventions of importance to the production and use of well-designed radar equipments have been made the subject of patent applications. The United States patents resulting from these applications will be widely held in industry, by foreign interests, by individuals, and by the Government. It is expected that a considerable block of radar patents, now held in a secret status in the form of applications in the Patent Office, will issue upon relaxation of the present security restrictions following the war.

Pending a reasonable adjustment of the patent situation which may require as long as ten years, it is expected that the following undesirable conditions will exist unless appropriate steps are taken now to avoid them:

1. Contractors will not be able to supply the services and the public with the most suitable designs of radar equipment because of adversely held patents.

2. A pyramiding of royalty rates will contribute to excessive costs of equipment.

3. A great amount of litigation will follow the issuance of patents.

PATENT POOL MAY BE SOLUTION

To overcome these conditions, it is recommended that the electronics industry either establish a radar patent pool for a period of ten years following the war, or work out some other satisfactory solution to the problem. The services and the public are entitled to the best-designed equipment that the state of the technical art is capable of providing. Moreover, the Government will not long acquiesce to the payment of pyramided royalty rates which represent a substantial portion of the cost of equipment, especially since practically all of this development has resulted directly or indirectly from the expenditure of public funds.

In order to look at the picture in proper perspective it is desirable, first, to consider just what dollar value of business probably is involved. A figure of $75,000,000 per year for several years following the war is probably representative of the volume of sales in the United States for radar equipment for Government and commercial purposes. All equipment utilizing radar techniques is included in this estimate.

A suggested pool, operating as a corporation, might be financed initially by a Government loan and organized by all of the electronics industry. The corporate structure of such a pool conceivably would comprise a board of directors, a corporation president selected by the board of directors, and a patent department, legal department, and accounting department, together with such officer, staff, and other assistance as may be needed. Membership would be limited to companies, agencies, or individuals who contribute patents essential to the operation of the pool and would continue during the useful life of such patents.

The successful establishment and operation of such an agency would require the full co-operation of all holders of major blocks of pertinent patents. This co-operation would have to be extended to a degree which would enable the management to make the enterprise attractive to the many holders of small blocks of patents whose enrollment as members is mandatory if all the benefits of pool operations are to be obtained. Foreign holders of United States patents essential to radar, of which there may be a considerable number, also should be admitted to membership under conditions to be determined.

The corporation, insofar as practicable, would obtain licenses under all radar patents considered essential to the manufacture, sale, and use of radar; all non-radar patents essential to such manufacture, sale and use; and the right to grant sublicenses under such patents in that field.

If the past policies of the Government in patent matters are any criteria of the future, I believe that the Government would license the pool upon a royalty-free basis under its considerable block of pending radar patents but would wish to retain any voting rights given members.

The corporation itself should determine the essentiality of any patent to the pool's operation. For carrying out this responsibility, it is proposed that an essentiality board be set up within the patent department. Provision should be made to permit any patent holder to present his case to this board, and, if a satisfactory showing of use by any licensee of the pool is made, the corporation may accept such patent holder as a member of the pool. Decisions of courts favorable to patent holders in infringement suits against licensees of the corporation also should be accepted as a showing of essentiality if, in the opinion of this board, such decision applies to the radar art.

The license granted the corporation by a member should provide that all essential patents held or acquired by such member be made available to the pool. It is contemplated that each member may himself become a licensee of the corporation upon his own request. The corporation should grant licenses only on condition that such licensees holding or acquiring patents essential to the art will themselves become members of the pool. The proceeds from operations would be distributed to each pool member in proportion to the value of patent rights which he contributes.

Infringement suits between pool members and licensees should be nonexistent, since, if any member can make a satisfactory showing of use of a patented invention in radar equipment manufactured, sold, or used by a licensee, such patent is itself available to the corporation and to its licensees. The same applies in the case of suits by licensees against pool members and by licensees who may not be registered as members, in the case of suits by such licensees against other licensees of the corporation. Exceptions to these cases conceivably might arise should the corporation decline to recognize the essentiality of a patent.

It is thought desirable to establish a legal department of the corporation, independent of the patent department, to provide legal services at no cost to members and licensees upon request in bona-fide radar patent matters, such as infringement suits by patent holders who are not pool members or licensees. In extending such legal services it is contemplated that members or licensees may prosecute their cases with legal assistance of the corporation or may request the corporation to prosecute their cases with such assistance as the member or licensee may give. While these legal services may be provided at no cost to the member or licensee, it is contemplated that the member or licensee will pay any damages assessed by an adverse decision in such a suit.

Except in the case of a contest between a member or licensee and a nonmember, it would be undesirable for the corporation to render legal assistance or otherwise engage in radar patent matters involving validity. The articles covering the operation of the corporation should provide that it take all necessary legal action against infringers of pool patents. Since such actions will be against nonmembers and nonlicensees, matters involving validity in such cases may be engaged in by the corporation.

A uniform royalty of six per cent of the selling price of radar equipment should be paid to the corporation by all licensees. This would not be excessive from the point of view of licensees since, through the operation of a pool system, they will be relieved of the need of paying pyramided royalties. This figure would be adequate to provide a reasonable financial return to members of the pool since the pool system will have greatly reduced expenditures by members which otherwise would have to be made for legal services, license management, and defending infringement suits, especially in the case of those members who are themselves radar manufacturers.

DISTRIBUTION OF PROFITS

The matter of how to distribute among members the profit from operations presents the most difficult problem to be faced in the operation of such a pool. It

is proposed that the corporation place patents in the following classes with reference to extent of use:

Class 5—Used in more than 75 per cent of the equipments sold by licensees in the preceding year.

Class 4—Used in 50 to 75 per cent of the equipments sold.

Class 3—Used in 25 to 50 per cent of the equipments sold.

Class 2—Used in 10 to 25 per cent of the equipments sold.

Class 1—Used in less than 10 per cent of the equipments sold.

This use classification is to be made by a patent-classification board. A member may request reconsideration of the classification of any patent at any time, and, if in his opinion an injustice has been done, he should be entitled to a hearing before the board.

While the most widely used inventions are generally the more basic and important ones, certain inventions enjoying restricted use may be of the greatest importance in their particular field of application and may not be circumvented by any known means. To satisfy the need for this kind of distinction, it is proposed that a weight factor be assigned to each patent by the patent-classification board. Weight factors also would be subject to review upon the request of the pool member concerned in the same manner as use classifications. Weight factors of 1.00, 1.25, 1.50, 1.75, and 2.0 are suggested. Except in the case of a small percentage of the patents, the largest weight factors will be associated with those patents having the highest use classification.

An alternate method to that just proposed might be used to simplify the work and profit distribution of the corporation. Radio Corporation of America, American Telephone and Telegraph Company, General Electric Company, and Westinghouse Electric and Manufacturing Company together probably would control about one half or perhaps more of the essential patents. It might be possible to reach an agreement with all the members whereby three per cent of the profits each year would be turned over to the foregoing group of major companies for distribution among themselves and the remaining three per cent distributed by the method previously mentioned. This alternate method would make it unnecessary to consider anything but essentiality in the case of patents held by these major companies to determine the equitable division of the three per cent of profits, and perhaps even this might be made unnecessary by agreement among members of the pool.

What will be the final solution to the radar patent situation cannot be forecast at the present time, but the matter is one which merits industry's full attention.

Navy's Electronics a Global Job

The installation and maintenance of radio, radar, and sonar equipment throughout the United States' fleets, on Marine amphibious vehicles, for naval air units, in permanent land stations, and for the more transitory faraway stations, which move with the fluid perimeters of the battle areas, are engineered from the electronics division of the United States Navy's Bureau of Ships. The installation and maintenance branch of the division in Washington, D. C., under Commander H. E. Bernstein does all the necessary planning and staff work.

When new equipment is to be installed on a certain class of ship, a careful study of the effect of the added weight on the stability of the ship as a whole must be made. The locations of the delicate equipment must be checked for possible interference or damage from other equipment, heavy guns, or exposure. Locations for antennas, for example, must be studied from a stability and interference standpoint. The first installations are observed closely so that the benefit of experience may be applied to later installations. After the equipment has been turned over to a Navy yard for installation the electronics division dispatches engineers, who are manufacturers' employees, to advise the yards in the use and handling of their products.

In addition, the electronics division has recruited a flying squadron of specially trained Navy technicians organized as the electronic field service group. These technicians are assigned primarily to absorb the impact of new programs or projects which would place too great a load on the normal facilities of the Navy yards and other installing agencies and to handle other emergency work. A picked group of these technicians travels with the fleet wherever it goes, transferring from ship to ship as the exigencies of the current situation demand. These men are trained in the installation and maintenance of the latest type of equipments and therefore are able to render prompt and able assistance to ship forces in solving their problems.

Maintaining air stations both for operation and training has become a major task of the division with the rapid expansion of the Navy's air arm. This shore activity alone is larger than the combined operations of all the commercial air fleets now extant in the majority of the Allied countries.

For the Marine Corps the electronics division is charged with installation and maintenance of its amphibious vehicles, its advance radio stations, and its control centers. Thousands of walkie-talkie sets and like equipment used by the Marines also are its responsibility. All communication equipment used between shore patrols and military police jeeps come under its jurisdiction.

The function of the electronics division in the maintenance of fleet electronic equipment involves four major activities. First is the direction of normal day-to-day maintenance by technicians aboard ship. Analysis of thousands of trouble reports each month gives a clue to types of preventive maintenance which will insure dependable operation at all times. Maintenance bulletins containing valuable information on preventive maintenance and trouble shooting are prepared by the division's engineers and distributed frequently to all naval activities.

Next is liaison with all schools engaged in training naval personnel in the installation and maintenance of electronic equipment used in the Navy. This liaison work includes advising training schools on the technical aspects of their curricula and supplying them with adequate amounts of the latest equipment.

Assisting repair facilities such as Navy yards as required in the emergency of repairing or replacing battle-damaged equipment is a third activity. Finally, many additional publications dealing with special installation and maintenance problems are prepared by the electronics division's engineers. These publications are aimed at improving the performance of radio, radar, and sonar equipment so that the fleet and naval establishment will have available, at all times, dependable up-to-the-minute electronic equipment.

In all, the electronics division of the Bureau of Ships is co-ordinating the efforts of approximately 75,000 workers, who have already installed almost $2,000,000,000 worth of electronic equipment and who are performing efficiently in the maintenance of this vast amount of apparatus.

Grounding Principles and Practice

III—Generator-Neutral Grounding Devices

A. A. JOHNSON
MEMBER AIEE

Characteristics of devices for grounding the neutrals of synchronous generators and the conditions under which the various types of devices are used and their effect on associated equipment are discussed in this article, the third in a series of five based on lectures which were sponsored by the power and industrial group of the AIEE New York Section during the 1943–44 season.

WHAT determines the desired characteristics of a generator neutral-grounding device? Under what conditions is each type of device best suited? How does the grounding device affect other generator protective equipment? Why do system characteristics have to be considered? These and other questions regarding the grounding of synchronous generators have been asked many times; this article provides many of the answers and attempts to present a practical solution of most application questions concerning usual neutral-grounding devices.

In the grounding of a generator, theoretical considerations, as well as experience and operating records, should be given considerable weight. A generator is a highly insulated, rugged piece of equipment, and a failure on a particular unit or its connecting leads, though possible, is not expected. To guard against this possibility of failure, protective relays are installed, phase-to-ground winding fault currents are limited to safe values, lightning-surge equipment is applied, and other precautions are taken.

In the event of a generator-winding or terminal-lead failure caused by excessive transient voltages, the method of grounding may appear to be absolved on the basis of available fault evidence. It is entirely possible, however, that the insulation might have been damaged and weakened at some time previous to the final insulation breakdown. This could be caused by an arcing ground on the generator terminals or by arcing between the generator-circuit-breaker contacts when the breaker operates. Thus the method of grounding should be scrutinized carefully to determine whether it might cause damaging overvoltages under any conditions.

The usual types of devices for grounding generator neutrals are:

1. Reactor (usually a low-ohm device).
2. Resistor (to limit current to about 1.5 times normal of generator, or less).
3. Small power (or distribution) transformer with resistor across its secondary.
4. Potential transformer or combination of several potential transformers.
5. Infinite impedance (neutral ungrounded).

REACTOR

In determining the reactor size, a single-phase-to-ground fault is assumed at the generator terminals. The object is to limit the fault current in the winding to that value which would result from a three-phase fault. Three-phase fault current is determined by using rated line-to-neutral voltage of the generator and its positive-sequence (subtransient) reactance. In determining the single-phase-to-ground short-circuit current, the positive-, negative-, and zero-sequence reactances must be known for the generator under consideration and for the system. These sequence reactances, X_1 (positive), X_2 (negative), and X_0 (zero) are usually given for new generators and can almost always be obtained for old machines from the manufacturer.

The following nomenclature will be used:

X_1, X_2, X_0 = sequence reactances of generator under consideration

S_1, S_2, S_0 = sequence reactances of system to terminals of generator under consideration including everything except generator being studied

X_R = reactance of neutral reactor

I_R = maximum rms current rating of reactor (in designing the reactor for mechanical strength it is assumed that the current is fully displaced due to d-c component)

Determination of X_R and I_R in Per Cent. Single-phase-to-ground faults have been classified into five groups in Figure 1 depending upon generator and system reactances. Group 1 is general and covers the case where all generator and system reactances are finite and different. This formula is formidable in appearance but it simplifies rapidly with actual values. Group 2 covers the case where system zero sequence is infinite and all other reactances are finite and different. Groups 3, 4, and 5 cover cases where two or more reactance values are equal; consequently, the formulas are considerably simplified as compared to the general case in group 1.

The formula for I_R in each case is for X_R of such a value as to make the machine-winding current on a single-phase-to-ground fault equal to the winding current on a three-phase fault. The voltage e in the formula for I_R is the rated generator terminal voltage expressed as 100 per cent. It should be pointed out that whenever X_1 and X_2 of a generator are equal, the minimum reactor reactance $X_R = (X_1 - X_0)/3$. This is true regardless of the system. The current through the reactor on single-phase-to-ground fault, however, depends on system reactance as well as generator reactances.

Turbogenerator Neutral Reactors. Figure 2 shows neutral-reactor currents given by the formulas of groups 4 and 5, Figure 1, and apply particularly to turbogenerators. They are plotted in terms of ratios; the ordinate is the ratio S_1/X_1 and the abscissa K is the number of times three-phase fault current e/X_1 which will flow through the neutral reactor. For each of the five curves the ratio S_2/S_1 is a parameter. The curves show at a glance the effect of system reactance on the neutral current during a single-phase-to-ground fault and also that S_1 and S_2 may be far from equal without appreciably affecting the neutral current I_R. The reactance of the grounding reactor is determined by the formula $X_R = (X_1 - X_0)/3$. To determine the maximum rms current I_R through the reactor determine S_2/S_1 and S_1/X_1 and find K from Figure 2. The current I_R equals $(K)(e/X_1)$ in per unit. Multiply per unit by 100 to get I_R in per cent.

Discussion. The reactance and current values for the neutral reactor must be checked for each system condition. A reactor which will protect the generator for all operating conditions must be applied. An example would be the application of a neutral reactor to a generator which at times is the only ground and at other times is operating in parallel with a grounding transformer. The reactor should also be checked with the generator operating as an isolated machine.

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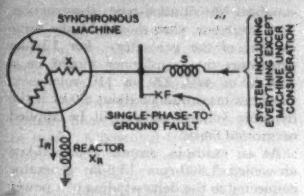

Figure 1. Determination of reactor characteristics

The reactance and current values for neutral grounding reactors under different conditions can be determined as follows, when the winding fault current for a single-phase-to-ground fault is made equal to the three-phase fault current:

Group 1—All reactance values finite and different

$$X_R = \frac{S_0(X_1X_2 + 2X_1S_2 - X_2S_2) + X_0(X_1S_2 - X_2S_2 - X_2S_0 - S_0S_2)}{3(X_2S_0 + X_2S_2 - X_1S_2 + S_0S_2)}$$

$$I_R = \frac{3S_0}{X_0 + S_0 + 3X_R} \times \left(\frac{e(100)}{\frac{X_1S_1}{X_1+S_1} + \frac{X_2S_2}{X_2+S_2} + \frac{S_0(X_0+3X_R)}{X_0+S_0+3X_R}} \right)$$

Group 2—$S_0 = infinite$; others finite and different

$$X_R = \frac{X_1 - X_0}{3} + \frac{S_2(X_1 - X_2)}{3(X_2 + S_2)}$$

$$I_R = \frac{3e(100)}{\frac{X_1S_1}{X_1+S_1} + \frac{X_2S_2}{X_2+S_2} + X_0 + 3X_R}$$

Group 3—$X_1 = X_2$; others finite and different

$$X_R = \frac{X_1 - X_0}{3}$$

$$I_R = \frac{3S_0e(100)}{(X_1+S_0)X_1} \left(\frac{1}{\frac{S_1}{X_1+S_1} + \frac{S_2}{X_1+S_2} + \frac{S_0}{X_1+S_0}} \right)$$

Group 4—$X_1 = X_2$; $S_0 = infinite$; others finite and different

$$X_R = \frac{X_1 - X_0}{3}$$

$$I_R = \frac{3e(100)}{X_1} \left(\frac{1}{\frac{S_1}{X_1+S_1} + \frac{S_2}{X_1+S_2} + 1} \right)$$

Group 5—$X_1 = X_2$; $S_1 = S_2$; $X_0 = finite$; $S_0 = infinite$

$$X_R = \frac{X_1 - X_0}{3}$$

$$I_R = \frac{3e(100)}{X_1} \left(\frac{X_1 + S_1}{X_1 + 3S_1} \right)$$

The value of X_R, as just determined, makes the generator winding current on a single-phase-to-ground fault equal to the winding current on a three-phase fault. The reactance may be larger than this further to limit the fault current, but it should not be increased without considering its effect on transient voltages during switching operations and arcing grounds. The ratio of X_0/X_1 on the terminals of the generator should be held to 4 or less to limit transient voltages. Special studies should be made if this ratio is greater than 4. Some discussion will be given later on transient voltages.

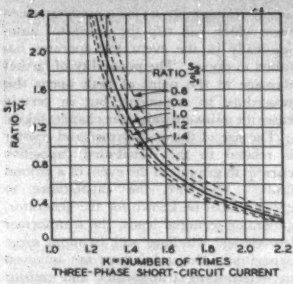

Figure 2. The currents in the neutral reactor for the indicated conditions may be determined from these curves

For
$X_1 = X_2$; $S_0 = infinite$
Then

$$X_R = \frac{X_1 - X_0}{3} \text{ in per cent}$$

$$I_R = (k)\frac{e \text{ in per cent}}{X_1} \text{ per unit}$$

In applying neutral reactors to generators which supply distribution feeders at generator voltage, the voltage to ground on the two unfaulted phases should be checked. This is particularly important on cable systems. The higher the value of grounding reactance, the higher will be the voltage to ground on the two unfaulted phases.

The current I_R in the neutral reactor will always be larger than the current in the faulted phase when the generator is connected to a system with other machines because zero-sequence current circulates through the system in the two unfaulted phases. If the generator is an isolated unit, with no transformer path for zero-sequence currents to flow, the current through the reactor will be the same as the current through the faulted phase or generator winding.

It is sometimes necessary to determine the reactor characteristics for several different-size generators operating in parallel. This must be considered specifically and calculations must be made to cover all possible combinations and arrangements of generators. A neutral reactor must be selected to cover the worst condition. If the machines are similar in every respect, the problem is greatly simplified. If the machines are sufficiently similar, and it is desired to operate only one unit grounded at a time, one reactor between the neutral bus and ground may be used for all machines; the desired machine should be connected to the ground bus through its neutral circuit breaker. When two or more generators connected to the same bus are grounded through low-impedance devices simultaneously, there is the possibility of excessive circulating currents between the generator neutrals. This point should be checked.

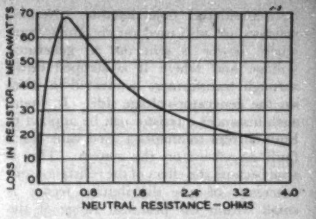

Figure 3. Power absorbed during single-phase-to-ground faults by different sizes of neutral-grounding resistors on a 31,250-kva 13.8-kv synchronous generator

RESISTOR

For practical application the ohms required in a neutral resistor can be determined by fixing the maximum desired ground current and dividing the generator phase-to-neutral voltage by this current. The generator reactance can usually be omitted.

$R = e/I$ ohms in resistor

The current through a neutral resistor is usually limited for large generators to a minimum of about 100 amperes and to a maximum of about 1.5 times the normal rated generator current. To limit the neutral current to 100 amperes requires an 80-ohm resistor for a 13.8-kv generator; above 80 ohms the resistor length usually increases, the same cross-section area being used for mechanical strength which necessitates a larger frame and more material. The other limit of 1.5 times normal rated current is desirable to prevent excessive loss in the resistor during single-phase-to-ground faults. A value of 1.5 times normal current through a neutral resistor gives a kilowatt loss of 50 per cent of the kilovolt-ampere rating of the generator. If the current is allowed to be several times full load by using a resistor of fewer ohms, the loss in the resistor may be several times the normal full load of the generator. This is illustrated in Figure 3 for a 31,250-kva 13.8-kv generator for a single-phase-to-ground fault on its terminals. A resistor of 0.47 ohm gives a loss of 68,000 kw. A sudden increase in load such as this may cause damage to the generator shaft and couplings to the turbine and may be detrimental to system stability.

One application of neutral resistors is in those generators which are connected directly to delta windings of step-up power transformers. In such instances full displacement of the neutral during a fault is

not considered objectionable. Neutral resistors are also used on certain systems where power is sent out at generated voltage and where it is stepped down through transformers connected in delta on the generator-voltage side. In many such instances a resistor can be applied to limit current to almost a fixed value for a fault anywhere on the system. This is true because the effect of the resistance and reactance of any distribution feeder is small within the practical range of the neutral resistor. This situation may be altered if current-limiting reactors are used in the feeders.

SMALL POWER OR DISTRIBUTION TRANSFORMER WITH SECONDARY RESISTOR

A generator may be grounded through a small power or distribution transformer, the secondary of which is shunted by a resistor to provide safe and economical phase-to-ground fault protection to the generator circuit. The transformer in this device serves only as a means of making a low-ohm resistor in effect a high resistance in the neutral. The transformer does not necessarily have to be placed directly under the generator because a separate vault or compartment near the generator can be provided and a single-conductor insulated cable run from the neutral of the machine to the transformer. The transformer is usually in the order of 25 to 50 kva, with a ratio which may be as high as 120 to 1. The current for a single-phase-to-ground fault on the generator terminals is usually limited by this grounding scheme to values in the order of ten amperes or less.

This scheme, Figure 4, is particularly adaptable for generators connected to delta transformer windings. Relaying of the generator for ground faults is accomplished by either a current or a voltage device on the secondary of the neutral transformer. In some instances, since the current which flows for a ground fault is small, some operators have delayed the tripping of the generator for a predetermined time to let the operator remove the generator load. This will prevent the sudden loss of one generator from the system and the disturbance which follows the abrupt dropping of generation. One method of doing this is to provide an alarm and a timing relay set for a predetermined time which will trip the generator automatically in the event the operator has failed to do so. The possibility of further damage at the point of fault opens this procedure to argument, but in certain cases the gains outweigh the chances taken.

The size of the transformer and resistor is related to the distributed capacitive current to ground in the event of a ground fault. Therefore, the capacitance to ground must be known for the generator, generator terminal leads, the transformer low-voltage winding, and terminal surge capacitors. Several factors are involved in determining transformer and resistor sizes. The practical result is to make the transformer current equal to the capacitive fault current and the resistor kilowatt loss equal to the capacitive fault kilovolt-amperes. This proportioning will avoid the ferroresonance possibility of an unshunted neutral transformer, prevent high transient voltages in case of arcing faults or switching, and will swamp harmonics present in the potential indication making possible a low setting for the ground relay.

The above proportioning also prevents false tripping of the relay as a result of phase-to-ground faults on the high-voltage side of the main power-transformer bank. For this fault location there will be a zero-sequence-voltage capacitive coupling through the main power transformer to the generator neutral. False tripping is avoided because the resistance and particularly the reactance of the ground transformer and resistor are relatively low compared to the coupling capacitance between the high- and low-voltage windings of the main power-transformer bank. If the neutral of the high-voltage winding of the power-transformer bank is grounded solidly, this condition will not cause trouble; but if the transformer neutral is ungrounded or grounded through a high-impedance device, there is the possibility of false tripping for low settings of the ground relay.

The grounding transformer for any generator will seldom be required to exceed a rating of about 50 kva and is of standard distribution-type construction. The insulation class should be the same as that of the generator. For 13.8-kv generators the transformer should be a 13.8 kv to 440, 220, or 110 volts even though a maximum of about 8.0 kv is the dynamic voltage which will be applied on ground faults.

As an example, assume a 62,500-kva air-cooled 1,800-rpm 13.8-kv generator connected to the delta winding of a power transformer through 200 feet of four 1,000,000-circular-mil 15-kv paper-insulated lead-covered cables per phase. The capacitance of the three phases of the generator is 1.05 microfarads; the capacitance of the cables is 0.49 microfarad; that of the power transformer is 0.04 microfarad; and that of the surge protective capacitors amounts to 1.50 microfarads. The total for all parts of the circuit is 3.08 microfarads. The total capacitive reactance will then be 860 ohms. With full line-to-ground voltage a total capacitive reactive power of 73.8 kilovars is obtained. A standard 50-kva 13.8-kv/230 volts distribution-type oil-filled transformer will be adequate for five minutes. The current through the primary winding of this transformer will be 9.27 amperes and the secondary current will be 556 amperes. Thus the resistor in the secondary must be designed to carry the current of 556 amperes for five minutes and have a resistance of 0.24 ohm to give a loss of 73.8 kw.

POTENTIAL TRANSFORMERS

A generator with a potential transformer in the neutral is grounded only through the capacitance to ground of the generator windings, bus work, transformers, cables, and surge capacitors. The potential transformer is only a device for measuring the voltage between the neutral and ground. To make certain that this is the case, the potential transformer must be liberally designed so that under no circumstances will its exciting current be appreciable compared with the circuit charging current to ground. If it is appreciable then a condition of ferroresonance may occur where the inductive reactance of the potential transformer as a result of saturation on overexcitation may approach the capacitive reactance and extremely high voltages may be present. Generally a

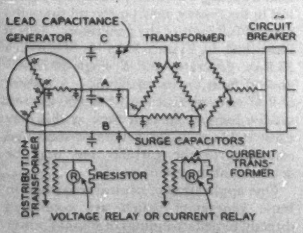

Figure 4. Distribution transformer with secondary-resistor grounding scheme

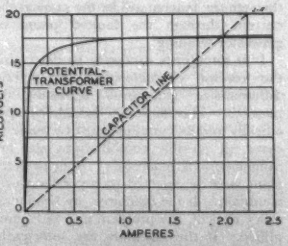

Figure 5. Ferroresonance condition with potential transformer in generator neutral

$jX_{PT} = j8{,}850$ ohms $\quad c = 0.3$ μf
$-jX_C = -j8{,}850$ ohms $\quad f = 60$ cycles

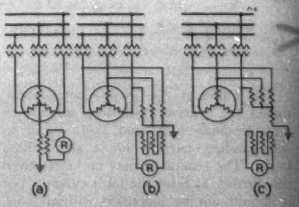

Figure 6. Potential-transformer ground detectors

potential transformer designed for line-to-line voltage placed in the neutral will be free from ferroresonance difficulties. However, if the potential transformers are to be applied on the terminals of an ungrounded generator, a voltage class higher than the line-to-line voltage ratings should be used. A potential transformer on the terminals of the generator will be liable to higher transient voltages than one in the neutral and, therefore, more apt to become involved in ferroresonance. Figure 5 shows how ferroresonance can take place; it occurs at 60 cycles where the exciting current for the potential transformer is equal to the shunt capacitive current. Potential transformers in the neutral or on the terminals will not prevent excessive transient overvoltages.

Three forms of ground-fault detection for generators may be had with potential transformers as shown in Figure 6. A single potential transformer, Figure 6a, may be used in the generator neutral so that a ground fault on the circuit comprising the low-voltage winding of the power transformer, connecting leads, or generator winding will produce a voltage on the relay for tripping or alarm purposes. Three potential transformers connected in star, Figure 6b, applied to the terminals of the generator will function in the same manner. This scheme has an advantage over one potential transformer because it can be set more sensitively. In addition, with three transformers, the machine will be tripped or an alarm will be given in case of an open circuit in the primary of a potential transformer. For a neutral potential transformer, if there is sufficient generator-circuit capacitance, the triangle of line voltage will tend to be stabilized with reference to ground and the residual harmonics will appear between neutral and ground. The relay must be set above any such harmonic voltage, which decreases its sensitivity and the protection of the generator windings near the neutral. Usually this will not be a serious handicap, although in extreme cases as much as 15 per cent of normal phase-to-neutral voltage might exist between neutral and ground. The scheme with three potential transformers avoids this situation.

In both of the foregoing uses of potential transformers the sensitivity of protection decreases as the ground fault approaches the neutral point. This is not often a serious handicap as most faults are on the generator terminals or near the line end of the generator winding. For complete protection within the generator windings a scheme which involves displacing the neutral continuously, Figure 6c, by means of an auxiliary winding on one potential transformer may be used. When a ground appears anywhere, even on the neutral lead, a voltage will appear across the relay.

As mentioned before, potential transformers properly applied serve only as

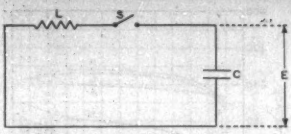

Figure 7. Capacitance–inductance circuit

Resonant frequency is $f = \frac{1}{2\pi\sqrt{LC}}$

voltage-measuring devices. Insofar as transient voltages caused by an arcing ground or switching of the generator circuit breaker are concerned, the generator is an ungrounded machine and therefore subject to the hazards of ungrounded operation. This situation may be improved in some cases by placing a resistor across the secondary winding of the potential transformer in parallel with the voltage relay.

Whenever potential transformers are used, there is some risk of false indication caused by ground faults on the high-voltage system as a result of the zero-sequence capacitive coupling between the high-voltage and low-voltage windings of the main power transformers.

INFINITE IMPEDANCE (NEUTRAL UNGROUNDED)

An ungrounded generator connected to a reactance-grounded system where X_0/X_1 is 4 or less is considered satisfactory from a transient-voltage standpoint. Where X_0/X_1 is greater than 4, it may be necessary to ground the generator to reduce materially the probability of excessive transient overvoltages. Where an ungrounded generator is connected to a resistance-grounded system, the resistance path is usually low enough in ohms to allow sufficient current to flow for relaying line-to-ground faults. Under these conditions it is usually safe to operate one or more generators ungrounded without fear of excessive transient voltages. In ungrounded generator operation the generator or generators are connected to an ungrounded system or to the delta winding of a step-up power transformer.

There are a number of objections to the operation of ungrounded generators (ratio X_0/X_1 infinite):

(*a*). It is not possible to relay for ground faults either in the generator or on feeders which may be supplied at generator voltage.

(*b*). It is possible for arcing ground faults outside the generator to develop transient voltages high enough to puncture generator insulation.

(*c*). Circuit-breaker operation may cause high transient voltages which may cause failure of generator insulation.

(*d*). Phase-to-phase faults are more probable than on a grounded generator. If feeders are supplied at generator voltage, two feeders may be tripped simultaneously by phase-to-ground faults on different phases.

(*e*). Feeders supplied at generator voltage will not trip for a broken wire which touches ground, thus constituting a public hazard.

TRANSIENT VOLTAGES ON GENERATORS

Transient overvoltages have caused the electrical failure of equipment and circuit insulation. Undoubtedly, there have been failures where these voltages were the cause but where the convicting evidence was destroyed. Generally lightning arresters are not recommended for protection against transient overvoltages; nevertheless, there are some situations where it is difficult to avoid depending on arresters for this protection. Evidence is available which shows that arresters have operated on transient overvoltages thus protecting equipment.

To explain the fundamental reasons for the production of transient voltages, refer to Figure 7. The capacitor C is charged by a direct voltage E after which the voltage is removed. When switch S is closed the capacitor will discharge through the inductance L and the circuit will oscillate at the resonant frequency determined by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

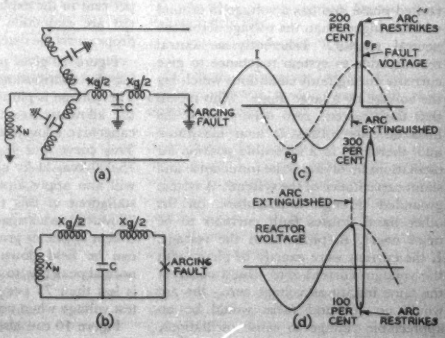

Figure 8. Arcing fault at the terminals of a three-phase generator grounded through a reactor

L is in henrys and C in farads. If the circuit has no loss, that is, no resistance, it will oscillate indefinitely. It is this oscillating, plus the normal circuit voltage, plus restriking, which enables high transient voltages to exist on a-c circuits.

Figure 8 shows a reactor-grounded generator and a phase-to-ground fault on one phase. Assume that the neutral reactor is large compared with the reactance of the circuit so that most of the voltage drop across the reactance in the circuit will be across the neutral reactor. Since the circuit consists mostly of reactance, the fault current will lag the voltage by about 90 degrees as shown in Figure 8c. Assume that at the instant the current is about zero the arc is extinguished, that is, the fault clears; then the voltage across the capacitance tries to assume the normal circuit voltage, but in making this attempt it overshoots to a point which is 200 per cent above ground. In other words, the circuit oscillates around normal voltage. The fault voltage indicated is also the voltage across the capacitor after the fault arc clears. If the insulation strength at the point of fault is such that the arc is re-established, the voltage across the fault drops from 200 per cent to zero and the capacitance voltage drops to a small value. The voltage across the reactor shown in Figure 8d goes from −100 per cent to +300 per cent. This takes place because of the reactance $X_g/2$ between the capacitance and the fault. If this reactance had been zero, the reactor voltage would go from −100 per cent to +100 per cent, and no more, at the instant the arc restrikes. The reactance $X_g/2$ between C and the fault is enough to allow an oscillation between the capacitance C and the two reactances in parallel. Most of the voltage drop will be across the neutral reactor and the voltage will oscillate from −100 per cent about normal voltage as reference and thereby reach a maximum for one restrike of 300 per cent. This voltage is across the neutral reactor; it can be seen that the instantaneous generated voltage on the two unfaulted phases must be added to the neutral voltage to get the maximum on the machine windings. The faulted phase also has a voltage to ground which is higher than the voltage across the neutral reactor. Inherently a neutral reactor adds to system reactance to give currents during fault conditions which lag the voltage by a large angle. This means that fault-current zero occurs when the instantaneous voltage is near maximum and, therefore, in a favorable position for oscillations involving series inductance and shunt capacitance of the system. A system grounded through a resistance, on the other hand, causes fault currents to be more nearly in phase with the voltage. If the current were exactly in phase with the voltage, current zero would occur at the same instant as voltage zero; the arc would go out and there would be no appreciable voltage to cause oscillations.

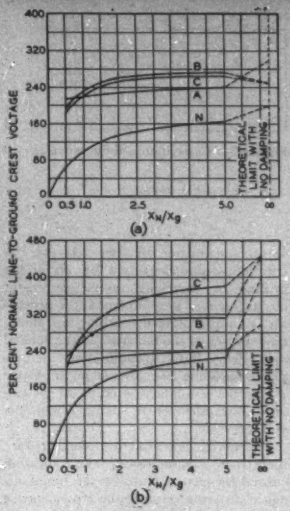

Figure 9. Effect of neutral reactance on transient voltages

(a). No restriking
(b). One restrike
A, B, and C represent line-to-ground voltages. N represents voltage across neutral reactor

With resistance grounding, fault currents actually lag the voltage by varying amounts, but the magnitude of voltage at the instant of current zero is usually small enough to prevent excessive transient voltages even if oscillations do occur. In addition, successive peak voltages during restriking are limited in magnitude due to the effect of losses in the neutral resistor.

Figure 9 shows line-to-neutral voltages which may be obtained on the various phases of a generator with reactor grounding. Figure 9a is for no restrikes and Figure 9b is for one restrike. These curves give voltages higher than the 300 per cent in the explanation above because the arc extinction voltage adds to the drops across the reactance and capacitance.

Figure 10 gives peak transient voltages for the distribution transformer scheme. The voltage is plotted against the ratio of the kilowatts loss in the resistor to the capacitive kilovolt-amperes of the circuit. This curve was made specifically for a 75,000-kva, 11-kv generator; however, it will also apply almost directly to all installations of this type. If the ratio of kilowatts loss to capacitive kilovolt-amperes is kept to one or greater, the peak voltage can be held down to about 2.6 times normal peak line-to-neutral voltage, which is less than 75 per cent of the generator test voltage when new.

Figure 10 can also be used to show the

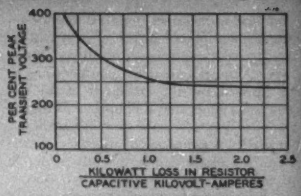

Figure 10. Maximum transient voltage during line-to-ground faults with distribution-transformer grounding scheme

magnitude of possible transient voltages on ungrounded or potential transformer grounded machines. In these cases the loss in kilowatts is very small so that the ratio of kilowatts loss to capacitive kilovolt-amperes is also very small, in the order of 0.2 or less. Thus, transient voltages of 4 to 5 times normal line-to-ground crest may be reached.

The discussion on transients has dealt with arcing phase-to-ground faults. The same phenomena can take place during switching operations where arcing takes place across the contacts when the switch is operated.

GROUNDING DEVICES FOR ONE OR TWO GENERATORS

Figure 11 shows a number of schemes for grounding a single generator. Each scheme is in use at present and each has a recommended application with the exception of the potential transformer. Figure 11a shows a low-reactance reactor where X_0/X_1 at the terminals of the generator is 4 or less; the reactor gives high phase-to-ground fault current for feeder relaying but minimum neutral displacement for circuit-insulation consideration. Figure 11b shows a resistor which limits the current to a maximum of about 1.5 times rated generator current and gives sufficient ground-fault current for feeder relaying but allows about full displacement of the neutral for single-phase-to-ground faults. The schemes of Figures 11c, d, e, and f are all workable layouts for unit system operation, but the two schemes using the distribution transformer are preferable because they limit single-phase-to-ground-fault currents to small values and at the same time protect the generator from excessive transient voltages. The potential transformer schemes of Figures 11g and h are not recommended because of the possibility of excessive transient voltages and ferroresonance. In Figure 11i the generator must be tripped immediately upon the occurrence of a phase-to-ground fault within the generator-differential-relay zone by differential relays. To give protection to the station service bank and the distribution feeder, these must be included in the generator-differential-relay zone or else must be provided with circuit breakers and sepa-

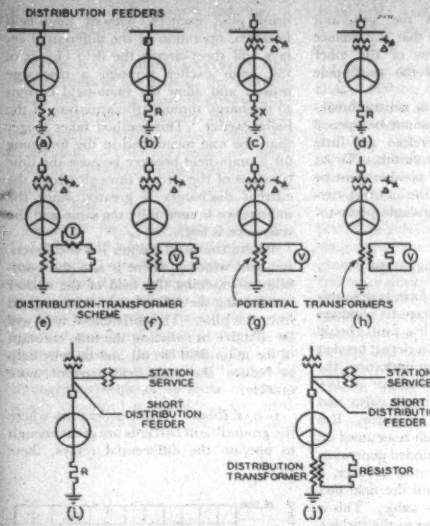

Figure 11. Grounding schemes for one generator

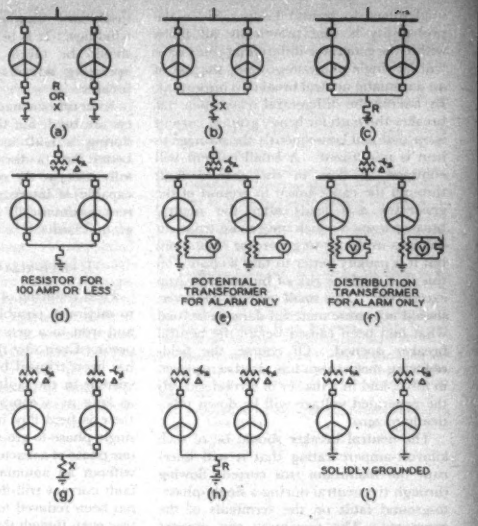

Figure 12. Grounding schemes for two generators

rate relaying. For this type of layout there are a number of questions regarding protection of all parts of the circuit. It is believed that the distribution transformer shown in Figure 11j provides satisfactory protection for ground faults. For phase-to-phase or three-phase faults other relaying must be provided for all parts of the circuit at generator voltage.

Schemes for grounding two generators are shown in Figure 12. The reasoning for a two-generator station is also applied to stations having a greater number of units. Figures 12a, b, and c are subject to the same limitations as one generator grounded through reactors or resistors. For a station with two or more generators it may be necessary to ground only one generator at a time to prevent excessive circulating current between the neutrals of the machines. When only one of several generators is grounded through a reactor, the ratio of X_0/X_1 should still be maintained at 4 or less. The ratio X_0/X_1 is determined from all sources at the terminals of a given generator and not solely from the constants of the generator being considered. Figure 12d is not a recommended grounding scheme because of the relaying problem for single-phase-to-ground faults. It can be used, however, by applying zero-sequence differential relaying to select a faulted generator. The fault current for this type of grounding would probably be too small for operation of the normal differential relays. Figures 12e and 12f show the use of grounding devices for alarm or indicating purposes as there is no selectivity between the two generators. A fault on one generator causes the operation of the ground devices on both generators. To get selectivity a grounding device must be used which will allow sufficient fault current to flow to operate the differential relays on the generator at fault. The schemes shown in Figures 12g and 12h are workable and must trip for ground faults on currents high enough to operate the differential relays. The solidly grounded scheme of Figure 12i is not recommended because of the high currents which will flow for single-phase-to-ground faults. In fact, for the last three cases it is recommended that a distribution transformer grounding scheme be used for each generator as in the case of a single machine.

GENERATOR PROTECTIVE EQUIPMENT

A discussion of generator grounding would be incomplete without comments on the effects of various grounding devices on generator protective equipment.

Differential Relays. Differential relays are used on most generators having ratings above 1,000 kva regardless of the method of grounding. They will disconnect the generator from the system for any type of fault within the protected zone provided sufficient current flows to operate the relays. The protected zone consists of the generator windings, generator leads, surge capacitors, if any, and the generator circuit breaker. A generator differential relay is insurance against excessive damage to the generator and as such initiates a number of operations for completely removing the unit from service. The following operations are usually performed:

(*a*). Trips main generator circuit breaker.

(*b*). Shuts off the steam supply to the turbine or the water supply to the waterwheel.

(*c*). Causes fire-extinguishing equipment to operate in the generator housing.

(*d*). Actuates the mechanism for reducing the main field flux.

(*e*). Trips neutral circuit breaker.

In those generators where high-impedance neutral devices are used, the differential relays will not operate for ground faults. A ground relay must be inserted in the neutral to perform the same function as the differential relays with perhaps certain modifications. For example, with a high-ohm resistor the neutral breaker will probably be omitted and, therefore, the neutral connection cannot be opened.

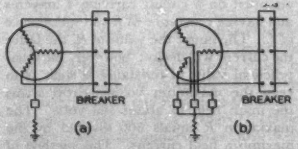

Figure 13. Generator-neutral circuit breakers
(*a*). *Single pole*
(*b*). *Three pole*

Neutral Circuit Breaker. The purpose of an automatic single-pole neutral breaker as shown in Figure 13 is to disconnect the neutral of the generator from ground on

single-phase-to-ground faults. Since the probability is that practically all faults within the generator-differential-relay zone will be single-phase-to-ground, the use of an automatic neutral breaker is important. By having the differential relay open this breaker the path for heavy ground current is opened and consequently the damage to iron is minimized. A small current will continue to flow in the ground fault through the capacitance to ground of the generator and leads after the neutral breaker is open which may cause transient voltages injurious to generator insulation; but it is usually better to take a chance on this than run the risk of burning the iron excessively. This small current, however, should not cause material damage beyond what had been caused before the neutral breaker opened. Of course, the field-reducing mechanism has also been placed in force, and in a matter of several seconds the generated voltage will be down practically to zero.

The neutral breaker should be of such kilovolt-ampere rating that it will interrupt the maximum rms current flowing through the neutral during a single-phase-to-ground fault on the terminals of the generator. The maximum rms current which will flow is more than the current through the faulted phase and can be determined from the formulas given in Figure 1. The voltage rating of the breaker should be the same as line-to-line voltage of the generator.

In an attempt to get better protection for generators grounded through low-impedance devices, the use of three-pole neutral breakers has been suggested as shown in Figure 13b. The advantages of using this breaker instead of a single-pole breaker are questionable and there are also certain major objections. A three-pole breaker costs more, and any operating difficulties may be very hazardous to the generator; if the breaker should be tripped accidentally, it would cause a generator outage; if one pole should open, it would cause single-phase operation of the generator which could be very serious and accentuate the problem of maintenance. Since more than 75 per cent of the expected faults are single-phase-to-ground, a single-pole breaker will interrupt the fault current. Transient overvoltages may be caused with both types of breakers although there may be a slight advantage on this point with a three-pole breaker. When the generator is tripped for single-phase-to-ground faults or any other type of fault, the field circuit is also tripped; and in several seconds the generator-field flux will decrease to a negligible value, thereby reducing fault voltage and current practically to zero. When a single-pole neutral breaker is used, some chance is taken because, after this breaker has opened and before the field flux has decreased to a low value, transient overvoltages may be produced on the ungrounded generator which could damage insulation elsewhere in the generator windings. It is believed that this chance should be taken in view of the other operating advantages of the single-pole breaker.

Sometimes nonautomatic neutral breakers are used, but these cannot be opened during a fault and therefore are little better than a disconnect switch. To be fully effective the neutral breaker must be capable of interrupting the neutral current automatically during single-phase-to-ground faults.

FIELD-REDUCING MEASURES

Field reducing of some form is desirable to minimize possible damage to windings and iron in a generator if a fault should occur. Even after the main circuit breaker has been tripped by relay operation, the current in the fault will continue to flow as long as a complete circuit exists and there is field flux in the generator. If a single-phase-to-ground fault is assumed on one phase of a reactor-grounded generator, without an automatic neutral breaker, a fault current will flow until the field flux has been reduced to a low value. This is true even though the power to the turbine may have been shut off completely, because the inertia of the machine is sufficient to keep the speed about normal for some time. Figure 14 shows current-decay curves for a 30,000-kva synchronous condenser; curve *a* is for condenser field opened on a discharge resistor and curve *b* is for opening the exciter field. For faults involving more than one phase, there will be a path for fault current either with or without the neutral grounded. Line-to-line or three-phase faults are very unlikely and very rare, but if one should occur, field reducing will limit burning of insulation, copper, and iron.

The simplest and most direct form of field reducing requires a main-field circuit breaker. When the differential relay or any other relay operates to trip the generator, the same relay should also actuate the tripping mechanism of the main-field breaker. This breaker is arranged so that a resistor is short circuited across the main field before its contacts actually part. The resistor will cause the field current to decrease in a shorter time due to the fundamental relation of $i = \epsilon^{-Rt/L}$, where the current i is flowing t seconds after the source of electromotive force is short-circuited on a circuit carrying I amperes and having resistance of R and inductance of L. The larger the value of R, the faster the current will decay; however, the usual practical value of resistance is such as to keep the maximum voltage drop across the main field to about 600 volts. The maximum R equals 600 divided by the maximum field current. This method of field reducing, however, cannot be used for a large number of generators because main-field breakers are not provided.

On generators with excitation systems using pilot exciters, without main-field breakers, operation of the differential relays will short-circuit the field circuit of the main exciter through a discharge resistor and allow the main-field current to discharge through the armature of the main exciter. This method takes longer than the one mentioned in the foregoing for a main-field breaker because the time constant of the circuit through which the current discharges is greater, since the inductance is essentially the same and the resistance is less.

Where the main exciter has a differential-field winding, there is also the possibility of opening the field of the exciter and leaving the differential field energized from the pilot. The differential field will be effective in reducing the time constant of the main-field circuit and thereby help to reduce the main-field current more quickly.

Ground Relays. On generators where the ground-fault currents are great enough to operate the differential relays, these

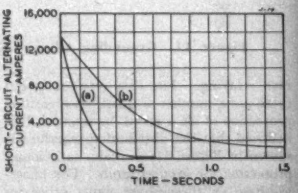

Figure 14. Calculated decay of fault current in a solidly grounded 30,000-kva 10-kv synchronous condenser

(*a*). *Main field short-circuited*
(*b*). *Exciter field short-circuited*

relays will clear the generator for all types of faults and ground relays are therefore unnecessary. In those instances where the generator or system is grounded in such a way as to limit the single-phase-to-ground fault current to small values, a neutral ground relay should be applied.

For most generators with ground relays, the generator trips immediately upon the occurrence of a fault. There are, however, exceptions where single-phase-to-ground faults are allowed to persist until the unit can be removed. In these cases an alarm is given, and in some applications a timer is set to trip the machine automatically after a predetermined time.

For a single generator connected to the delta winding of a transformer where a resistor or a small power transformer with a secondary resistor is used, a current or voltage relay may be used to trip the generator for a single-phase-to-ground fault. A current transformer with a current relay is usually placed at the grounded end of a neutral resistor. A current or voltage device may be used in the second-

ary; with the small power transformer, if it is a current device, a current transformer will be needed.

Where two or more generators with neutral resistors are bussed, the machine which has a single-phase-to-ground fault may be selected and tripped by means of zero-sequence current relays connected differentially. One zero-sequence measurement is required in the neutral of each generator and one on its terminal at the common bus.

Capacitors for Surge Protection. For 11.5-kv and 13.8-kv grounded generators, one standard one-fourth-microfarad capacitor unit is recommended on the generator terminals, whereas for generators in the ungrounded classification two standard one-fourth-microfarad units are recommended. In general, for surge capacitors, any generator grounded through a resistor of 50 ohms or less or solidly grounded is considered grounded. Generators having a reactor, a potential transformer, a small power transformer, or no ground should be considered ungrounded.

Lightning Arresters. For all generators about 1,000 kva and larger, special station-type lightning arresters should be used at the generator terminals. For generators less than 1,000 kva, special station-type arresters are usually too costly but special line-type arresters may be applied economically. In all cases, standard line-type arresters or protector tubes should be placed on every overhead line entering the station at generator voltage. Ungrounded generators or generators grounded through resistance devices require a higher-voltage-rating arrester than generators grounded solidly or through low-reactance devices. Both line- and station-type arresters must be applied on the basis that the rms voltage from line to ground across the arrester under any normal or fault condition does not exceed the arrester phase leg rating.

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Wide-Band Program-Transmission Circuits

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Broadcasting stations employing frequency modulation require circuits from studios to transmitters and between network stations that are capable of transmitting wide frequency bands in order to realize the high-fidelity characteristics of this system. Postwar plans of telephone companies include consideration of such requirements; considerable progress already has been made in building the necessary plant.

GROWTH of frequency-modulation broadcasting was interrupted by the war. The present interest in frequency modulation indicates a resumption of activity and an expansion of this type of broadcasting soon after the war ends. A recent review showed that applications have been filed with the Federal Communications Commission for more than 250 frequency-modulation broadcasting stations scattered throughout the United States. Among other things, these stations will need communication channels between main studios, from studios to transmitters, and from remote pickup points. The telephone companies have provided these for standard broadcast stations in the past and they are providing such facilities today for frequency-modulation stations now in operation.[1]

With extensive development of frequency-modulation broadcasting, it is possible that new and different types of facilities may be found desirable. However, the extent of such communications facilities and the desired characteristics can only be developed with time. Presumably the broadcasters will formulate their needs as soon as the requirements are more clearly visualized. Depending on the way these requirements develop and are affected by varying local situations, they may cover quite a range of conditions and types as is the case in standard broadcasting. Fortunately, the various types of facilities which the telephone companies furnish today, or can furnish in the future, likewise cover quite a range—a range which appears adequate to meet any likely requirements for frequency-modulation broadcasting. The selection and arrangement of facilities will be done in the future as frequency-modulation broadcasting grows. However, the postwar plans now are being evolved and it is desirable, therefore, to review the available facilities and to outline some of the factors which may be worthy of consideration in formulating such postwar plans.

Essential substance of a paper presented at a joint meeting of the communication group of the AIEE New York Section and the New York section of the Institute of Radio Engineers, October 4, 1944.

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STUDIO–TRANSMITTER CIRCUITS

Since the beginning of radio broadcasting, the telephone companies have provided studio–transmitter circuits, transmitting up to 5,000, 10,000, and even to 15,000 cycles. Introduction of frequency modulation in itself does not impose any severe transmission problems for circuits of this type.[2]

The FCC Standards of Good Engineering specify that studio–transmitter circuits for frequency-modulation broadcasting stations should transmit satisfactorily a band from 50 to 15,000 cycles. There are about 45 commercial frequency-modulation broadcasting stations in operation today. All but six of them are using wire lines between studios and transmitters and these circuits are giving satisfactory service.

To take care of future requirements for circuits of this type is not expected to be very difficult. Generally the transmitters are not far from the studios and suitable circuits can be provided on wire lines over existing telephone routes. In a few cases, where the transmitter location is at a

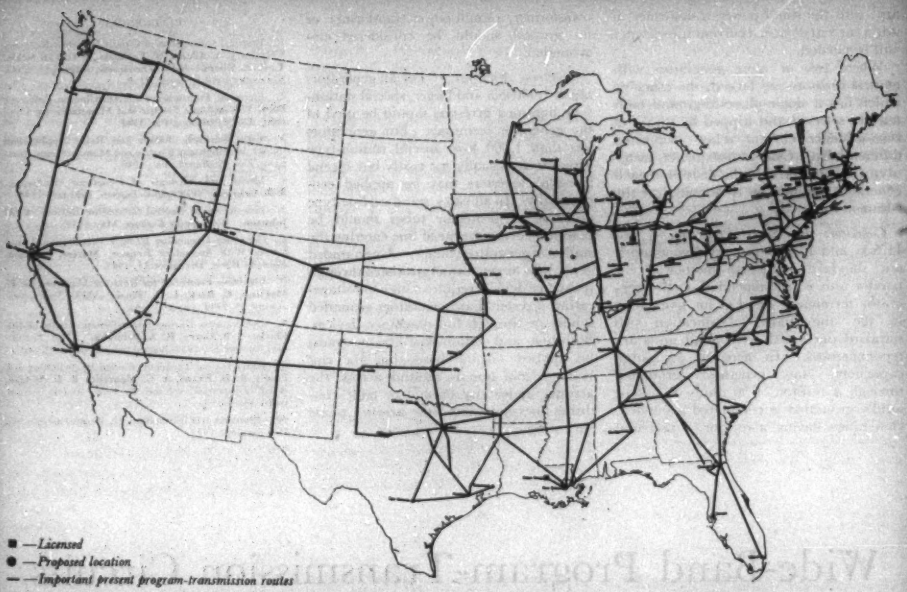

Figure 1. Proximity of projected frequency-modulation broadcasting stations to present program-transmission routes

rather inaccessible point in rugged country, some special construction may be required to establish the channel. For some of these unusual cases, the use of radio may well be the best way to provide the circuits. More will be said later about the possible use of radio for communication purposes under such conditions.

LOCAL PICKUP CIRCUITS

The local circuits for picking up programs originating outside the studio also are being provided as required. For these circuits regular telephone plant is adapted for frequencies up to 15,000 cycles.

INTERCITY NETWORK CIRCUITS

Present-day radio service would be well nigh impossible if each broadcasting station originated in its own studios all the programs it transmits. There would not be enough Toscaninis or Charlie McCarthys to go around. An intercity network provides a means of making readily available to any broadcasting station on the network the best talent in any city reached by the network. This pooling of programs gives the best over-all coverage for the public and at the same time makes the average cost of such high-grade programs less to individual stations.

OBJECTIVES FOR NETWORKS

Broadly speaking, the objectives for network facilities to interconnect frequency-modulation broadcasting stations are much the same as for facilities to interconnect present-day stations. The more important of these would seem to be:

1. Transmission characteristics which will assure naturalness. This involves a satisfactory frequency band, adequate volume range, and freedom from appreciable distortion and noise.

2. Ready availability. There are distinct advantages in having the facilities engineered and installed in advance of need so that they may be put into actual use on reasonably short notice.

3. Flexibility. It is desirable to be able quickly to change the layout in order to broadcast special events or, perhaps in the middle of a program, to change the point of origin from the Atlantic Coast to the Pacific Coast.

4. Reliability. Adequate stand-by facilities are essential so that in case of failure of any link in the network, service can be restored with little interruption to the broadcast. Also, in case of storms, floods, fires, or other disturbances which might affect a particular route, it is desirable to have facilities available on another route to protect the service.

5. Co-ordination. For satisfactory results it is necessary that the nation-wide layout be built up in accordance with an over-all plan and that each link be designed so that it will fit into the layout with little change. Several typical examples will illustrate this:

(*a*). Providing satisfactory transmission on extensive networks requires close and continuous co-ordination of design, maintenance, and operation. Facilities which provide acceptable transmission between New York and Pittsburgh, for example, might prove wholly unsatisfactory for coast-to-coast network operation unless they were designed with that in mind.

(*b*). Tolerable over-all distortion may be apportioned in some approximate manner to individual sections for use as a guide in laying out these sections. However, the real problem arises when these separate links are switched together to set up the extensive network and this requires over-all tests and adjustments.

(*c*). The equipment and methods used to compensate for cumulative distortion depend upon the characteristics of the individual circuit links connected together at a particular time. The individual links switched together in this manner vary from hour to hour. It will be evident that the problem of co-ordination to assure suitable over-all transmission becomes much more difficult if the individual links are designed and maintained independently of each other.

TYPES OF CIRCUITS

The transmitted frequency band for intercity program circuits varies depending upon the grade of service the broadcaster wants. The following classifications cover most of the circuits used at present:

1. From about 300 cycles to approximately 2,500 cycles, suitable for transmission of speech only.

2. From about 200 cycles to about 3,500 cycles, suitable for transmission of medium-quality program material over limited distances.

3. From about 100 cycles to about 5,000 cycles.

4. From about 50 cycles to about 8,000 cycles.

Circuits used for program transmission require individual design consideration. In many cables now in plant, the intercity program circuits are operated on carefully segregated pairs that are specially loaded

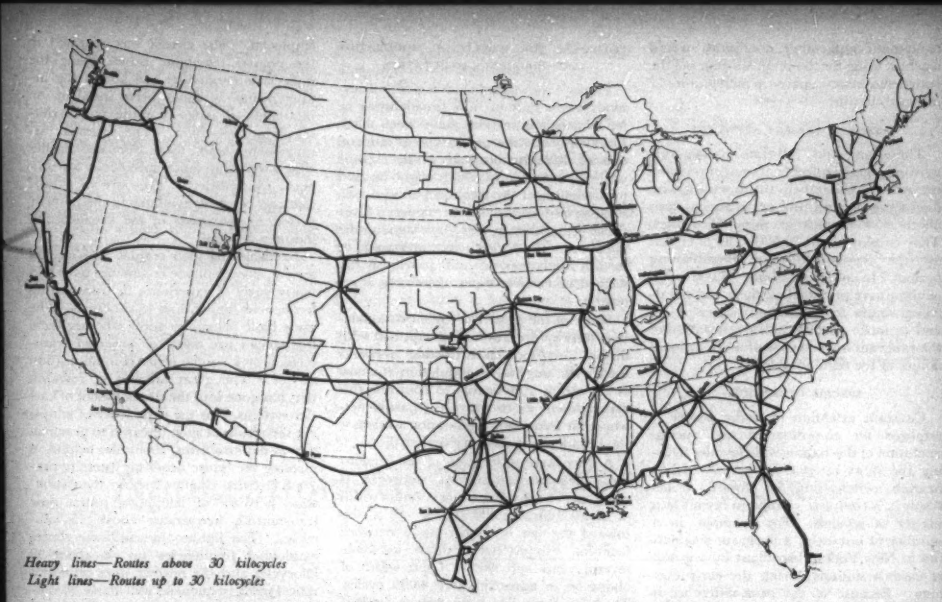

Figure 2. Intercity routes transmitting frequencies to 30 kilocycles or higher

and equipped with special amplifiers. Though much of this plant was installed more than ten years ago, it was so arranged that the facilities can readily be equalized to 8,000 cycles for circuits thousands of miles long and somewhat beyond 8,000 cycles for shorter circuits. This was done in anticipation of the possible need for higher-quality circuits by the broadcasting industry.

In recent years there has been a trend toward broad-band carrier systems in the telephone plant. With the cable carrier system, a block of frequencies extending up to 60,000 cycles is subdivided to obtain 12 telephone circuits.[3] The same frequencies are employed in the two directions, transmission in opposite directions being in separate cables. The cables may be either aerial or underground. On most of the newer cable routes, such as between Omaha and Sacramento, the two cables required are buried directly into the ground with a plow train which installs both cables and closes the trench all in one operation. On the older routes existing cables have been adapted for carrier transmission. Broad-band cable carrier systems are now in operation on more than 8,000 miles of route including Portland to Atlanta on the east coast; the transcontinental cables from New York through Chicago and Denver to San Francisco and Los Angeles; and important north–south routes from Chicago to San Antonio and from Chicago to Atlanta. It is now possible to talk entirely over cable carrier facilities from Portland, Me., to Los Angeles and very soon to San Diego.

A somewhat different broad-band system is used on open-wire routes.[4] It is similar to cable carrier in that a wide band of frequencies provides 12 circuits; it differs from cable carrier in that both directions of transmission are on the same pair of wires, which makes it necessary to use frequencies extending up to nearly 150,000 cycles.

The latest and broadest-band system to date is the coaxial system. With this the 12-channel group is used as a building block.[5] Five of these are first put together to form a supergroup of 60 circuits; next the wide bands of frequencies for eight such supergroups (480 circuits) are modulated so as to place the frequencies in different ranges and they are then located side by side in a frequency band several million cycles wide. This is transmitted over the cable, is amplified and equalized at intervals of about five miles, and is then subdivided again at the far end into 480 individual circuits.

What has all this to do with intercity program circuits? The point is that facilities of this kind may be used for program circuits to interconnect broadcasting stations. All these broad-band carrier systems employ in common the principle that a wide band of frequencies is subdivided to obtain 12 telephone circuits. For use with such carrier systems, special carrier program terminal equipment arrangements have been developed which enable a program circuit to be obtained by using the frequency space normally occupied by one or more message telephone circuits. Changes are not required in the line conductors and associated equipment. The number of telephone circuits displaced depends upon the frequency-band width desired for the program circuit. In the future, a program circuit may employ as much of this broad frequency band as the broadcasters believe is warranted.

The carrier program terminals as now designed are capable of providing circuits with band widths of 5, 8, or 15 kilocycles. Up to the present the equipment has been used only with the cable carrier system but it can be adapted to use with other broad-band systems.

Two varieties of carrier program terminal equipment have been developed:

1. A single-side-band system which is arranged so that several channels of the regular 12-channel group may be used for a program circuit, the remaining channels continuing to be used for message toll circuits.

2. A double-side-band system which employs less costly terminal equipment but uses the frequency space normally occupied by 12 message circuits.

Both arrangements should be useful after the war. The single-side-band system is likely to be preferable for the longer circuits because it permits more efficient use of line frequency space. The double-side-band arrangement would have advantages where the cheaper terminal

equipment and other conditions would warrant using for the program channel the entire frequency space available for 12 message circuits.

EXTENT OF PRESENT NETWORKS

There are four full-time nation-wide networks, plus a number of smaller regional networks. Altogether, the intercity wire lines serve on a full-time or occasional basis about 830 stations in some 550 cities. They employ about 90,000 miles of circuit for the regular full-time broadcasting period. In addition, about 45,000 miles of circuit are provided on these and paralleling routes to handle part-time services and to make possible quick restoration of the program in the event of an occasional failure of the regular layout.

SPECIAL OPERATION

Constant attention of many people is required for co-ordination and special operation of this nation-wide layout. During the short interval for station identification, switches may be required which result in a complete change in layout in a matter of seconds. For example, in a number of instances, a program originating in New York is broadcast by a group of eastern stations during the early evening. Because of the time difference it would still be afternoon in the Pacific Coast area. The program therefore is not broadcast by the far-western stations but is repeated for them from New York several hours later. For this second transmission all the stations in the east, which had broadcast the same program earlier, are disconnected from the network. Frequently these stations are connected to some other network section to permit broadcasting another program. In addition, switches are often made almost instantaneously during a program to change the point of origin—perhaps to employ talent in all parts of the nation in launching a war-loan campaign. Full-time monitoring of the program is done at certain key points on the networks, supplemented by part-time monitoring at other points.

The people engaged in co-ordination of the intercity layout are located in all parts of the nation and the nature of their work requires that they use uniform methods and have instantaneous communication between many points. Many thousands of miles of telephone and telegraph circuits are used exclusively in operation and maintenance of the program networks.

It will be evident from this brief description that provision of a smoothly working network of facilities to interconnect broadcasting stations involves more than the establishment of circuits between various cities. The arrangements for providing and operating such networks have been developed by the telephone companies over a period of years and these are available for use in extending the service to other areas as frequency-modulation needs may require.

NETWORKS FOR AMPLITUDE MODULATION AND FREQUENCY MODULATION

Figure 1 shows the location of frequency-modulation stations now broadcasting or for which applications have been filed. Practically all these are in or near cities on existing intercity program routes. Some of the present routes which might be used to interconnect the frequency-modulation stations are shown in the figure. Over these and other routes, not shown, the telephone companies are prepared to furnish the types of circuits previously described and newer types of services as required.

Some of the present frequency-modulation stations are now being supplied with distant programs over existing networks used with amplitude-modulation stations. It is entirely practicable to continue this arrangement or to provide separate networks for frequency-modulation stations if the broadcasting industry desires them.

A very large proportion of the present-day program-transmission networks is made up of circuits having a band width of about 100 to 5,000 cycles. As a step toward the use of higher-grade network facilities, circuits were made available several years ago with a band width of about 50 to approximately 8,000 cycles. Thus far there has been only a limited demand for these facilities. It may be that more use will be found for these or still wider band circuits as frequency-modulation broadcasting grows.

Looking toward such a possibility, the Bell System has carried on a program of research to develop better techniques and to improve quality so as to keep pace with the needs of the broadcasting industry. Periodically special demonstrations have been given of the results of such work.

A preview of some possible program network facilities of the future was given 11 years ago by the Bell Telephone Laboratories in a demonstration of auditory perspective between Philadelphia and Washington.[6] As the name auditory perspective implies, this preserves the spatial relationship of the original sounds so that an audience listening to the reproduced program experiences the same sense of depth as would an audience listening to the program at its origin.

For this demonstration, the Philadelphia Orchestra played in the Academy of Music in Philadelphia and the program was transmitted over the telephone cable to Washington and reproduced there before an audience in Constitution Hall. Three separate channels, each equalized to 15,000 cycles, were employed in this demonstration of higher-fidelity three-dimensional transmission and reproduction.

Another demonstration of the practicability of providing wide-band program circuits, this time over long distances, was given before a meeting of the AIEE at Philadelphia in 1941.[1] In this instance a 15,000-cycle circuit 1,200 miles long was employed. The circuit was operated in the regular telephone cables, using the same type conductor and amplifying arrangements as have been installed on thousands of miles of route for carrier-telephone operation. The terminal arrangements were those discussed earlier which were developed specifically for program transmission. They are of a type that can be made available in the postwar period as the needs of the broadcasting industry develop.

In furnishing their regular message toll service, the telephone companies have had many years of experience in transmitting frequencies higher than 15 kilocycles. The same basic principles apply whether these frequencies are used for program transmission or for some other communication service. The great amount of research that has gone into the development of carrier systems, plus the experience of adapting the results of such research to practical day-to-day problems, should be helpful in meeting the future needs for intercity program circuits. Figure 2 shows the nation-wide network of telephone routes now transmitting frequencies above 15 kilocycles. The lighter lines indicate routes employing frequencies up to about 30 kilocycles and the heavier lines represent routes using frequencies well above 30 kilocycles. Some are open-wire routes and some are cable routes. Together they form a network that fairly well blankets the populated regions of the United States.

LOOKING TO THE FUTURE

In the near future many routes will transmit frequency bands millions of cycles wide with high fidelity. The band width allotted to a particular circuit is a matter of design and depends on the intended use of the circuit. With the coaxial cables now being installed, the same cable may carry circuits hundreds of cycles wide for telegraph, several thousand cycles wide for message telephone, circuits still wider for program networks, and, finally, circuits millions of cycles wide for television. The Bell System tentative program for extension of coaxial cables during the next five or six years involves some 6,000 to 7,000 miles of new cables extending across the nation. This program is already well under way; coaxial cables have been installed from New York to Washington, Stevens Point, Wis., to Minneapolis, and Atlanta to Macon, Ga. Cable is now available to extend this to Jacksonville. The Terre Haute–St. Louis cable is being installed and the securing of approvals from various governmental departments is now in process for the Washington–Charlotte, Atlanta–Meridian, and Dallas–Shreveport cables, the first three links in the proposed extension of coaxial cable from New York to the Pacific Coast.

RADIO-RELAY TRIAL

In addition to the several types of wire systems described, development work is

in progress to make use of radio for this service. Experience with wire-line systems has indicated that program circuits can best be provided on the same open-wire lines and in the same cables with message telephone circuits and other communication channels. The Bell System has obtained approval to make an experimental installation of a radio-relay system between New York and Boston to determine if the radio system could handle a very wide band of frequencies which might be subdivided for various services such as message telephone, program circuits, and television circuits in much the same manner as is done with coaxial cable.

If this trial proves successful, the telephone companies in the future would expect to use radio links in program circuits where that method of transmission seems preferable to wire-line methods.

CONCLUSION

The question of how much band width to assign to a program transmission circuit depends on the requirements of the broadcasting industry. Whether the proper design objective for intercity circuits to connect frequency-modulation stations together is precisely 15,000 cycles, or higher, or lower, is uncertain at the moment. As stated earlier, the present extensive program networks are made up largely of facilities equalized to 5,000 cycles. However, if the broadcasters decide that they want circuits wider than 5,000 cycles, the telephone companies will be able to supply them, whether the demand be for 8,000 cycles, 10,000 cycles, 15,000 cycles, or even higher.

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Applications of Thevenin's Theorem

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FELLOW AIEE

TEXTBOOKS in communication engineering indicate that engineers in this field are aware of the fact that Thevenin's theorem offers a very convenient tool in the solution of electric-circuit problems. Electrical engineers in other fields, however, do not seem to have made a very thorough acquaintance with this theorem, which in many instances can be of considerable help in the solution of their problems. It is the purpose of this article to show by means of some examples from various fields how the theorem can be put to practical use.

Thevenin's theorem can be stated in several ways, of which the following is the most common. The current in any single branch of a network consisting of any number of impedances and voltage sources can be found in the following manner: open the branch under consideration and determine the open-circuit voltage appearing across the break; then consider all voltage sources as short-circuited or—if they have internal impedance—replaced by an impedance equal to the internal impedance of them and calculate the impedance of the network under this condition when looking into the two terminals of the break. The current that will flow in the branch under consideration after closing the break will be the open-circuit voltage divided by this impedance.

Sometimes the theorem is stated in the following manner: so far as any particular branch of a network of impedance elements and voltage sources is concerned,

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In the solution of electric-circuit problems, little advantage has been taken except in communication work of the help that may be obtained by the application of Thevenin's theorem. Statements and proof of the theorem and examples of its use are given in this article.

the network can be replaced by a single voltage source equal to the open-circuit voltage that would appear if the particular branch in question were removed from the network and in series with this voltage source an impedance that would be measured across the two terminals of the branch in question (but with this branch removed) and all voltage sources in the network either short-circuited or replaced by impedances equal to their internal impedance.

The proof of Thevenin's theorem rests entirely on Helmholtz's theorem of superposition; as a matter of fact, Helmholtz may have discovered Thevenin's theorem some 30 years before the latter. The principle of superposition states that in a network consisting of a number of linear impedances and a number of voltage sources, the total current distribution can be found by first determining successively the current distributions due to each voltage source acting alone in the network with all other voltage sources replaced by impedances equal to their internal impedance (that is, short-circuited, if the internal impedance is zero), and then superimposing all these current distributions on each other. The correctness of this method is self-evident because each current distribution so found will satisfy Kirchhoff's laws and consequently the superposition of all of them will also satisfy these laws. The proof of Thevenin's theorem on the basis of the superposition principle is given in the appendix.

EXAMPLE 1

Four 24-volt d-c relays, with a current consumption of 0.1 ampere each are to be operated from a voltage divider connected to a 230-volt line. It has been ascertained experimentally that an application of 30 volts to the coils of the relays will not lead to undue heating. Figure 1A shows the actual setup. Obviously the voltage divider should be designed so that with all relays energized, the voltage across them will not be below 24 volts, while with one relay only energized, it should not rise above 30 volts. The four relays can be considered as a variable load, and Thevenin's theorem states that as far as this load is concerned, the actual network of resistances could be replaced by a single voltage source equal to the open-circuit voltage E' with all load removed and a resistance in series with this voltage equal

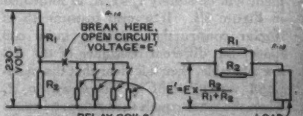

Figure 1A

Figure 1B

to the parallel resistance of R_1 and R_2. This is indicated in Figure 1B.

When the load consists of all four relays, the voltage across it should be 24 volts and the current will be 0.4 ampere. When it consists of one relay only, it is permitted to rise to 30 volts and the current then will be 0.125 ampere. Therefore a current change of 0.275 ampere can be accompanied by a voltage change of six volts. Since this "voltage regulation" of the voltage divider obviously is due only to the parallel resistance of R_1 and R_2 as shown in Figure 1B, it is possible immediately to write the equation

$$\frac{R_1 \times R_2}{R_1+R_2} = \frac{6}{0.275} = 21.82 \text{ ohms} \qquad (1)$$

The open-circuit voltage or fictitious supply voltage E' in Figure 1B is simply equal to the load voltage plus the drop occurring across the parallel combination of R_1 and R_2. With four relays operating, the load voltage must be 24 volts and the drop occurring across R_1 and R_2 equals $0.4 \times 21.82 = 8.73$ volts. Therefore E', or the open-circuit voltage of the voltage divider, must be $24+8.73=32.73$. This gives a second relation between R_1 and R_2:

$$\frac{R_2}{R_1+R_2} = \frac{32.73}{230} \qquad (2)$$

and introduction of this value into equation 1 immediately yields

$$R_1 = 153.33 \text{ ohms and } R_2 = 25.44 \text{ ohms} \qquad (3)$$

EXAMPLE 2

In Figure 2 a Wheatstone bridge is shown operating from a supply voltage E and an indicating instrument with the resistance R_g in the bridge arm. The internal impedance of the source is considered as negligible compared to the resistances of the four arms of the bridge. It is desired to find the current through the instrument. For application of Thevenin's theorem, the branch containing the instrument is opened. The voltage e across the break will be

$$e = E\times\left(\frac{R_3}{R_1+R_3} - \frac{R_4}{R_2+R_4}\right)$$
$$= E\times\frac{R_2R_3 - R_1R_4}{(R_1+R_3)(R_2+R_4)} \qquad (4)$$

The resistance measured across the break with E short-circuited will be

$$R = R_g + \frac{R_1\times R_3}{R_1+R_3} + \frac{R_2\times R_4}{R_2+R_4} \qquad (5)$$

The current flowing through the instrument will be simply $I_g = e/R$, as indicated in Figure 2B. If several instruments of similar construction (that is, same coil space) but different resistance of the coil are available, then it is clear that the maximum wattage will be developed in R_g when the latter equals the bridge resistance as measured between the points A and B with the instrument removed and E short-circuited; obviously this is equal to the sum of the two terms following R_g in the preceding equation for R. In some books the erroneous statement is made that if a galvanometer near the optimum resistance is not available, the addition of a series resistance to the instrument or a shunt resistance parallel to it so that the total resistance of the combination is equal to the bridge resistance will increase the sensitivity. By inspection of the preceding equations and of Figure 2B, it is quite obvious that the wattage in a given instrument certainly cannot be increased by placing an additional resistance in series or in shunt to it.

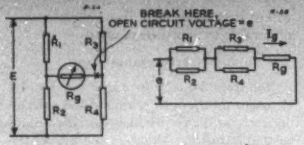

Figure 2A Figure 2B

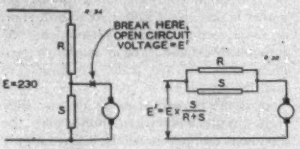

Figure 3A Figure 3B

EXAMPLE 3

The slowing down of d-c motors by means of armature control has the well-known disadvantage that a removal of the load may cause the motor to speed up to practically full speed. To avoid this, it is the usual practice to place an additional resistance across the armature. In a recent paper[1] the following instance is treated. A ten-horsepower 230-volt 1,150-rpm d-c shunt motor is to be slowed down to 45 per cent of the full-load motor speed under a condition that the load demands 34 per cent of full-load torque referred to the ten-horsepower motor. It also is required that the speed shall not exceed 66⅔ per cent of the full-load speed if all load is removed from the motor shaft. In the paper the following simplifying assumptions, perfectly permissible for all practical purposes, are made: the torque is proportional to the current, the induced voltage is proportional to the speed, and under full-load condition, the IR drop in the armature is ten per cent of the line voltage.

In Figure 3A the diagram is shown. By application of Thevenin's theorem, as stated in the second form, to the branch containing the motor armature, it may be seen that so far as the armature is concerned, the effect of the voltage divider R–S is the same as if the armature were connected over a series resistance to a fixed voltage equal to the open-circuit voltage appearing across S; this series resistance is equal to the parallel combination of the two resistances R and S, since this would be the resistance measured across the break with the line terminals short-circuited; as far as the armature is concerned, the circuit shown in Figure 3A can therefore be replaced by the one given in Figure 3B.

According to the data given, the IR drop in the armature at full load is 23 volts, which means that the induced voltage at 1,150 rpm is equal to 207 volts. At 66⅔ per cent of full-load speed, the induced voltage will consequently be ⅔ of 207 volts, which equals 138 volts. Since it is demanded that the motor shall not exceed this speed under the no-load condition, the open-circuit voltage of the voltage divider R–S, or the fictitious supply voltage E' of Figure 3B, must not exceed 138 volts. This leads immediately to the equation

$$\frac{S}{R+S} = \frac{138}{230} = 0.6 \qquad (6)$$

With the assumption that the product of the current and the induced voltage becomes converted into mechanical energy, the full-load current of the motor will be

$$I_{FL} = \frac{10\times 746}{207} = 36 \text{ amperes} \qquad (7)$$

At 34 per cent of full-load torque, the motor current will consequently be $0.34 \times 36 = 12.25$ amperes. At 45 per cent of full-load speed, the induced voltage will be equal to $207 \times 0.45 = 93.15$ volts, while the IR drop in the armature at 34 per cent of full-load current will be 34 per cent of 23 volts, which equals 7.82 volts. Therefore the armature must be supplied with a voltage equal to the sum of these two last-mentioned voltages, that is, 100.97 volts. With reference to Figure 3B, this means that the parallel combination of the two resistors R and S must have a value such that a current flow of 12.25 amperes causes a drop of voltage from 138 down to 100.97, that is, 37.03 volts. This leads therefore to the following equation:

$$\frac{R\times S}{R+S} = \frac{37.03}{12.25} = 3.022 \qquad (8)$$

Introducing into equation 3 the value of $S/(R+S)$ from equation 1 results in

$$R \times 0.6 = 3.022 \text{ or } R = 5.04 \text{ ohms} \qquad (9)$$

With R known, equation 1 then yields for S a value of 7.56 ohms. The small discrepancy of these values from those given in the paper is due partly to a difference in the assumed value for the full-load current and to a small amount of inaccuracy in the graphical solutions in the paper.

EXAMPLE 4

In Figure 4A, let R, S, and T represent the three phases of an unbalanced three-

phase system with the three phase voltages E_1, E_2, E_3 shown in the vector diagram, Figure 4B. Let the three impedances z_1, z_2, z_3, as shown in Figure 4A, form an unbalanced three-phase load for this system. It is desired to obtain the current flowing in z_1. Breaking the branch z_1 produces an open-circuit voltage across this break equal to the voltage between phase T and the junction of the two impedances z_2 and z_3, which are seen to be series connected between the phases R and S, that is, across the voltage E_1. The open-circuit voltage across the break will consequently be

$$E_{01} = E_3 + \frac{E_1 \times z_2}{z_2 + z_3} = \frac{(E_3 + E_1)z_2 + E_3 z_3}{z_2 + z_3}$$
$$= \frac{-E_2 z_2 + E_3 z_3}{z_2 + z_3} \qquad (10)$$

The impedance measured across the break with all phase voltages short-circuited is equal to the impedance z_1 plus the parallel impedance of z_2 and z_3, that is,

$$Z = z_1 + \frac{z_1 \times z_3}{z_1 + z_3} = \frac{z_1 z_2 + z_1 z_3 + z_2 z_3}{z_2 + z_3} \qquad (11)$$

The current through z_1 after closure of the break will be given by

$$I_1 = \frac{E_{01}}{Z} = \frac{-E_2 z_2 + E_3 z_3}{z_1 z_2 + z_1 z_3 + z_2 z_3} \qquad (12)$$

This solution is identical with the one that would have been obtained by applying Kennelly's transformation to the wye system of impedances, transforming them into a delta. The current I_1 would then be simply equal to the sum of the two currents in the two legs of the delta adjacent to phase T. The latter solution assumes that one has the transformation formulas either in his head or in a nearby handbook.

For additional examples dealing with a-c network problems, as well as a general discussion of the theorem and a proof of it, see reference 2.

EXAMPLE 5

Thevenin's theorem is not limited to the steady-state conditions but can also be used for the solution of problems involving transients. In Figure 5 let the capacitor C be discharged and then let it be connected through switch S to the voltage divider R_1–R_2. It is evident that the capacitor will finally reach a voltage equal to the open-circuit voltage existing across R_2, that is,

$$E_{C\max} = E \times \frac{R_2}{R_1 + R_2} \qquad (13)$$

Again, as far as the capacitor is concerned, the voltage-dividing network and the supply voltage can be replaced by a fixed voltage equal to the open-circuit voltage across R_2 as given in equation 13, and a series resistance equal to the parallel combination of R_1 and R_2. The well-known exponential relation between the instantaneous voltage across the capacitor and time as given by

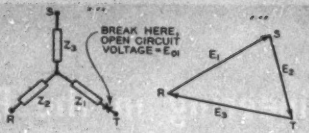

Figure 4A Figure 4B

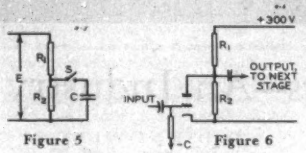

Figure 5 Figure 6

$$e = E_{C\max}(1 - e^{-\frac{t}{T}}) \qquad (14)$$

is therefore valid. The time constant, however, is given by

$$T = C \times \frac{R_1 \times R_2}{R_1 + R_2} \qquad (15)$$

When making use of Thevenin's theorem for the solution of transient problems it is necessary, however, to be sure of one condition: the open-circuit voltage across the break must be independent of the frequency of the supply voltage. This condition will obviously be satisfied only when the network, exclusive of the branch in question, is made of the same type of impedances.

EXAMPLE 6

Suppose that in a resistance-coupled amplifier, grid-bias conditions are such that it would be most desirable to operate a particular stage consisting of a type 6J5 tube with a plate-supply voltage of 100 volts and a load resistance of 40,000 ohms; the high-voltage supply for the amplifier as a whole is 300 volts. Such a condition is quite often satisfied by placing a relatively heavy bleeder across the total supply, tapping the bleeder at the desired voltage, and then placing the load resistor between the tapped point of the bleeder and the plate of the amplifier tube. Since Thevenin's theorem tells us that a voltage divider acts like a fixed-voltage source and a resistance in series with it, it is obvious that we can design the bleeder to fit the individual stage. With reference to Figure 6, R_1 and R_2 simply have to be chosen so that the open-circuit voltage across R_2 equals 100 volts, which gives the relation:

$$\frac{R_2}{R_1 + R_2} = \frac{100}{300} \qquad (16)$$

while the parallel combination must equal 40,000, which leads to

$$\frac{R_1 \times R_2}{R_1 + R_2} = 40{,}000 \qquad (17)$$

Substitution of equation 17 into equation 16 gives $R_1 = 120{,}000$ ohms and $R_2 = 60{,}000$ ohms. This solution represents not only the highest economy obtainable as far as the amount of bleeder current is concerned, but also results in the elimination of one resistor.

It must not be assumed that the application of Thevenin's theorem makes every circuit problem an easy one. If there are numerous meshes, the opening of one branch will still make calculation of the current distribution in the remaining ones a difficult one. The preceding examples show, however, that in simpler networks its application not only will reduce the numerical work but also will aid in visualizing the influence of the various circuit parameters on the solution of the problems.

Appendix

Assume that in a network consisting of linear impedances $z_1, z_2 \ldots z_n$ and voltage sources $E_1, E_2 \ldots E_m$, it is desired to determine the current flow in z_k. Upon opening this branch, an open-circuit voltage E_{k0} will appear across this break and the current i_k, of course, will be zero. Now suppose an additional voltage source of exactly the magnitude of the open-circuit voltage and opposing the latter is introduced across the break. This obviously will not change anything from the open-circuit condition of the branch z_k as far as the rest of the network is concerned. There is now a network with no open branches but with a new voltage source equal to E_{k0} introduced into the network. The current distribution in the network now is determined by the original m voltage sources plus the new voltage E_{k0}. But under the new condition the branch current in z_k is zero, and, according to the superposition principle, the current distribution resulting in the network from the introduction of E_{k0}, with all other voltage sources short-circuited, must be such as to cancel exactly the original current in the branch z_k. The current flowing originally in z_k therefore must be equal to a current that would be flowing if all original voltage sources were short-circuited but a voltage source equal to but opposite in polarity to E_{k0} had been introduced into the branch z_k. This proves Thevenin's theorem. Incidentally, the proof also points the way to an important extension of the theorem: while the theorem is essentially a tool for finding the current in one branch only, the current in other branches can be found by superimposing on the current distribution in the network with branch z_k open the current distribution which results from the introduction of the voltage $-E_{k0}$ in this branch, with all other voltage sources short-circuited.

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XI—Electronics—An Industry Comes of Age

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MEMBER AIEE

TO PREDICT the future of a new science is much like predicting the future of a new-born child. The conception date is usually a matter of record and the appearance of the "first working model" is an event. From then on, to carry the analogy farther, the thing develops and the parents or the inventer continually wonder what it will be when it grows up. During the first few years it is the most marvelous thing in the world—later, when it reaches the adolescent period, there sometimes are doubts. Usually in the end, if it has been handled properly, it reaches maturity, finds its rightful place in the world, and becomes a useful member of society. Its rate of development and the soundness of its growth depend on many things. A too rapid growth may produce "soft wood" that will not weather the storm. By expecting too much of it, or glamorizing it, one may spoil the whole thing.

War, as is well-known, hastens development tremendously. Youths leave home just kids and almost overnight they are men—hard, capable, self-reliant, and ready to take any responsibility put upon them. So it is with the sciences also. War has resulted in the development of communication, aviation, synthetic rubber, plastics, and electronics at probably 10 or 20 times the rate it would have developed in peacetime. Some of the growth is "soft wood." It is too expensive, too bulky, and in some cases too complicated. These instruments will be refined as soon as the pressure of war is gone and will find their place in our peacetime economy.

Let no man forget that electronics has played a vital role in this war—so vital in fact that it is to be hoped that the subject will be given suitable comprehensive treatment when the war is over.

There seems to be no generally accepted definition of electronics. To the engineer it may be defined as "the practical use of the flow of electrons through space." Thomas A. Edison (United States patent 307,031, 1883) observed that electricity flowed between a hot filament and a plate in an evacuated envelope when the plate was positive and that no measurable current flowed when the plate was negative. This indicated that the particles of electricity that traversed the space were charged negatively. It was not until 1891 that G. Johnstone Stoney named the particle the electron. In the meantime Fleming, Elster, Geitel, J. J. Thomson, and others had studied the flow of these particles and the latter especially had experimented with cathode-ray tubes. The cathode-ray tube, an essential part of the modern television set, thus was one of the first electronic tubes with which experiments were performed. This is true also of the photoelectric tube which is equally essential not only to television but to many other applications such as talking motion pictures, and a host of industrial instruments.

Although born in the early 1900's, electronics—meaning "the practical use of the flow of electrons through space"—developed relatively slowly until World War II caused a great burst of growth. Its place in the postwar world will depend upon its ability to do things better, cheaper, or faster than they can be done by other means.

Books have been written on the history of electronics so that obviously it cannot be covered here. Starting about 1900 experimenters too numerous to mention started turning their thoughts seriously toward the practical application of the flow of electrons. In the absence of an official "birth certificate" it may be guessed then that electronics was born in the early 1900's. Electronic-tube developments came fast and furiously. Rectifiers, photoelectric tubes, oscillators, amplifiers, cathode-ray tubes, x-ray tubes, thyratrons, ignitrons, protective gaps, current regulators, voltage regulators, the iconoscope, the electron microscope, the mass spectrometer, and other electronic devices were developed and perfected in the nation's research and engineering laboratories.

Corresponding groups of engineers and research men developed the circuits and systems for putting these devices to work. This joint effort of the electron-tube designer and the circuit engineer has of course been responsible for the development of the field of electronics.

Electronics has grown up—it has passed the glamour stage and in the future competitive market it will have to stand on its merits. It is being put to work and will be used, generally speaking, only when it can do something cheaper, faster, or better than can be done any other way. Statistics are not too accurate at the present time but it is estimated that the annual sales of electronic equipment have increased from around $275,000,000 prior to the war to well over $4,000,000,000 now.

RADIO

Radio has been and probably will be for some time the greatest field for the application of electronics. This is to be expected since it meets, to a greater degree than any other application, the requirements defined hereinbefore, namely, that it can accomplish a result cheaper, faster, and better than can be done by any other means.

The sale of broadcast receivers increased from 4,500,000 sets in 1929 to nearly 14,000,000 in 1941. The war, of course, sharply curtailed the manufacture and sale of sets after that. During this same period the average price per set came down from $136 to $30.

The sale of commercial receivers and transmitting equipment increased from about $6,000,000 in 1931 to nearly $14,000,000 in 1939 and for 1942 it has been estimated at $550,000,000. A New York financial house estimates the 1943 total to

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be $4,000,000,000 including military equipment. The latter estimate must be considered only as a rough approximation. It serves to show principally the tremendous task accomplished by electronic manufacturers and to give at least an inkling of the progress that has been made in the development and manufacture of electronic equipment during the war.

This experience and the facilities to produce will of course be applied to peacetime products after the war.

Tubes have been developed to generate frequencies far beyond anything available before the war. This greatly relieves the crowding of the spectrum and makes room for frequency-modulation transmission, television, and peacetime applications of radar and other special forms of communication and detection.

At the time this article was written it was reported that nine commercial television stations have been licensed, 60 applications are pending, and many more are coming up. Broadcasting will most certainly be improved probably along more than one direction. Refinements will be made in the present amplitude-modulation stations and the use of frequency modulation will expand as more stations are built. Millions of home receivers now creaking to a standstill because they cannot be repaired or tubes for them cannot be obtained may never be repaired at all. Americans want the best there is and the best has not yet been made.

It is the writer's personal opinion that many of the detection devices now used in the war effort eventually will be required on all airplanes and ships just as most states require shatterproof glass in automobiles, and for the same reason—safety.

Insurance that airplanes will not run into mountains, that ships will not collide in the fog, and that they can land or dock safely in any kind of weather will give travel another increment of security.

A great deal of development will be required in this field. This equipment has mushroomed into a reality overnight. It will have to be made cheaper, smaller, lighter, and in some cases more reliable.

It would seem inevitable that a device that enhances man's sense of vision so that he can see at night, through smoke or fog, is so necessary that its continued development and use is assured. Sometimes we marvel at the human beings' ability to speak, hear, and see, and take for granted what science has done to enhance these faculties. With radio waves and electronics harnessed together we throw our voices around the earth, hear reports direct from the battlefield on the other side of the earth, see television pictures in our living rooms direct from the scene of action, and now are able to "see" objects through darkness, smoke, and fog.

Electronic control has increased production of capacitors at the Westinghouse Electric and Manufacturing Company and has reduced spoilage of critical metal foil. Even a beginner operating this winding machine will produce as many capacitors in a day as 24 operators would by hand-wound methods

ELECTRONIC HEAT

The development of high-power high-frequency tubes and equipment for radio and other war uses, coupled with unprecedented demands for production, has led to the use of high-frequency power for producing heat. For example, the war produced unheard of demands for tin plate and also the war made tin hard to get—a bad combination. It was found that if tin was fused onto the surface of a metal strip that about one-third as much tin was required as when it was applied by conventional methods. High-frequency electronic generators were used to produce heat directly in the plate by induction. Tin plate is produced by this method at speeds approaching 1,000 feet per minute. The major suppliers of tin plate are using this process and the radio-frequency power used in these plants far exceeds the total power used in all the broadcasting stations in the western hemisphere.

The manufacture of penicillin is a vitally important process. It is reported that electronic heating produces concentrated purified pencillin in 30 minutes instead of the 24 hours required by the previously used process.

Induction and dielectric heating by means of high frequency has this outstanding characteristic—the heat is generated inside the body. By properly designing the body and the power-input coupling the heat can be put where it is needed most. It will not take the place of gas and coal in domestic furnaces nor is it likely to be used in kitchens for domestic cooking or heating water. Like all other electronic applications, it will find its proper place doing specialized jobs cheaper, faster, or better than can be done by other means.

Commercial cooking, canning, and food sterilization seem to be definitely "in the wood." Dehydration of foods electronically results in more complete removal of moisture with less loss due to spoilage and rancidity. Incidentally, while electronic tubes make high-frequency induction and dielectric heating practical, it may not be so generally known that induction heating has for years been used to make electronic tubes, and that there are many other applications in tube production. In order to evacuate the tube completely of all gases it is sealed onto a vacuum system and while it is being exhausted high-frequency coils surrounding the tube heat up the internal parts and drive out gases and moisture, essentially the process used in dehydrating foods except that the frequency used in the latter process is usually higher. Rectifiers supply d-c power to the oscillators that furnish the heating current. Vacuum and temperature are measured by electronic devices. The power used in treating and testing tubes is often run through an electronic inverter and fed back into the power lines instead of being thrown away. Electronic spot and seam welders are used to weld the tube parts together, and an electrostatic precipitator is used to clean the air in the assembly room. Many electronic instruments are used to take measurements, effect automatic control of process, and for inspection and sorting of parts and materials.

Dielectric heating is certain to have an

important position in the bonding of plywood and the heating and curing of plastic materials. It has its important application when thick sections of plywood, thermoplastic, or thermosetting materials are involved. The development of thermosetting bonding materials together with the use of dielectric heating now permits the fabrication of thick sections of plywood in a matter of three to five minutes. Hours were previously required with steam or other forms of applied heat. The same is true in the heating and curing of plastics. In addition to speed, the electronic method does a more thorough and uniform job.

There are many more applications of induction heating of metals besides the tin-flow application previously mentioned. With induction heating faster and more uniform heat treating, annealing, brazing, soldering, and tempering are made possible. It is possible by proper choice of frequency and equipment to case harden the desired surface of mechanical parts such as gears and shafts and leave the base metal tough and malleable. The chief merit of electronic heating in all these cases comes back to the fact that it is possible to control it accurately and "put the heat where you want it," and quickly.

So far the application of induction and dielectric heating has been limited mostly to war jobs. After the war the field is bound to expand and applications made that now cannot be foreseen.

SPOT AND SEAM WELDING

The amount of sheet-metal fabrication going on in the United States is of course enormous. Sheet-metal parts have been put together with rivets, various kinds of fasteners, bolts, and so on. Soldering, brazing, and arc welding are often used. Following the invention of the ignitron, however, the use of electronically controlled spot and seam resistance welding has expanded at a rapid rate and the field is probably only scratched. By means of electronic timers the amount of current put through the weld, the exact length of time that current flows, and even the point on the cycle at which current starts can be controlled accurately. As a result, thousands of welds can be made identical so that there is very little danger of spoiling the work. A good criteria of the quality of such welding is the fact that overlapping welds or seam welding is used to make vacuum-tight joints in large electronic tubes such as metal ignitrons. Resistance welding of oil drums, tank cars, and metal airplanes is already in use.

It is to be expected that when plants convert after the war many of them will adopt electronic welders instead of drilling holes for rivets or for bolts and screws.

RECTIFICATION AND INVERSION

This is one of the largest and most important fields of application for electronics. It can be disposed of rather quickly, however, because the functions are so well known. Rectification is the conversion of a-c to d-c power and inversion is just the reverse, namely, the change of d-c power into a-c power or the change of a-c power from one frequency to another, such as changing 60 cycles to 25 cycles. Inversion is not extensively used now but probably will become more and more prominent, especially in the industries where a variable frequency is needed for variable-motor-speed control.

The operator is shown using the telephone channel on this carrier-current system. Various panel units are arranged to suit the needs of each particular installation. There are ten independent audio waves available for as many different functions

Enormous rectifier capacity has been installed during the war to supply d-c power to the aluminum, magnesium, steel, and electrochemical industries. At the beginning of 1940 all industries had about 500,000 kw of installed rectifier capacity and this was an accumulation of installations covering a period of approximately 15 years. In the three years following 1940 five times that amount or 2,500,000 kw of rectifiers have been purchased in the United States and 1,000,000 kw in Canada.

Most of the new rectifier equipment is of the ignitron type. Its merit lies in increased efficiency and reliability. Ignitron rectifiers now give and will continue to give motor generators very stiff competition.

Rectifier business alone in the United States has totaled about $120,000,000 in the last five years. Much of this has been in big units. The future will see the development of a potentially bigger market by the introduction of smaller units to reach the smaller power consumer.

CARRIER CURRENT

The term carrier current as used here means "making power-transmission wires do the double job of carrying information as well as electric power." During the war, of course, it is doubly significant because in addition to reducing costs it has saved strategic materials such as copper. The operation of protective relays with information provided by carrier current in combination with high-speed circuit breakers makes it possible to remove short circuits from systems in times as short as $^1/_{30}$ second. This not only releases system capacity but also eliminates burning out of the equipment and undesirable system disturbances. The following is an illustration of what carrier current can do. Two transmission lines, costing $6,000,000. each, were shown to have their capacity increased nearly 50 per cent as a result of installing carrier-current equipment and associated apparatus costing about $50,000. In other words, the addition of this equipment to existing lines eliminated the need for building a third line which would have cost another $6,000,000.

This business has totaled about $3,500,000 in the last five years and continued development would seem to insure its growth. The potential possibilities of sending information over existing power lines deserve serious consideration.

FURTHER APPLICATIONS

As it is recalled that electronics can convert electrical power into any desired form and can switch power accurately and quickly and do it efficiently, it is realized instantly that it can be used for all kinds of control purposes. Welding control, motor-speed control, voltage regulation, automatic synchronization, inspection, and counting are only a few.

Air cleaning is developing into a major application. The electrostatic precipitator is used for cleaning dirt, oil, and other particles from the air in precision war plants and in the motor rooms of steel mills. It is an infant in the electronic field but destined to grow up very fast when restrictive orders on critical materials are lifted.

Specialized electronic instruments like the electron microscope and the mass spectrometer give the research laboratories and industrial plants new tools to work with. The former expands microscopy into fields not previously touched and the mass spectrometer makes it possible to analyze gases and vapors with a speed and accuracy not otherwise attainable.

One fact must be reiterated—electronics is not a cure-all. It must be applied only where it can do things better, cheaper, or quicker than can be done otherwise. There are plenty of places where it can do just that.

INSTITUTE ACTIVITIES

Winter Technical Meeting Held in New York; Buffalo and Detroit Meetings Canceled

The AIEE 1945 winter technical meeting was held in New York, N. Y., January 22–26, as planned, but in compliance with the recent wartime ban on conventions the North Eastern District meeting scheduled to be held in Buffalo, N. Y., April 25–26, and the summer technical meeting scheduled for Detroit, Mich., June 25–29, have been canceled. As in previous national and District technical meetings held since Pearl Harbor, primary attention at the winter meeting was devoted to war problems.

Registered attendance was 1,718 as indicated in an accompanying tabulation. This was somewhat higher than last year's total, but considerably less than the record registration of 1,931 at the Philadelphia winter meeting in 1941.

Some 80 papers were presented at the 21 technical sessions covering a wide variety of subjects; 10 informal technical conferences on diversified subjects rounded out the program. Electric machinery was the subject of four sessions (one of which concerned machine insulation) and one conference. Three sessions and one conference were sponsored by the committee on power transmission and distribution; at the latter, wartime practices on distribution systems and their effect on system operation and future designs were discussed. Three sessions also were devoted to industrial power applications, one of which covered industrial control, and one conference, which dealt with industrial-system and apparatus voltage ratings.

Electrical applications to aircraft occupied two sessions and one conference. An all-day conference on polyethylene high-frequency cables was sponsored by the committee on communication in co-operation with the Army–Navy Radio-Frequency Cable Coordinating Committee. Available brief reports of the sessions and conferences are included in succeeding pages.

Following the custom of many years, the Edison Medal was presented during winter-meeting week—to E. F. W. Alexanderson (F '20) of the General Electric Company. The presentation was made at a joint evening session with the Institute of Radio Engineers. At the same session, Captain J. B. Dow of the United States Navy delivered an address on the Navy electronics program.

"Research and Its Effect on Winning the War" was the subject of an address by J. Carlton Ward, Jr., of the Fairchild Engine and Airplane Corporation, at the general session. Other features of the general session were presentation of the Alfred Noble prize to W. R. Wilson (A '43) of the General Electric Company, and presentation of Honorary Member certificate to Past President Dugald C. Jackson, professor emeritus of Massachusetts Institute of Technology. A smoker held Tuesday evening at the Hotel Commodore drew a capacity crowd of 1,668.

As is customary during winter-meeting week, the Institute's board of directors met as did many of the committees and subcommittees. Available reports of these meetings are presented in succeeding pages.

COMMITTEES

The committee responsible for the success of this year's winter meeting was headed by J. F. Fairman; other members included F. A. Cowan, W. S. Hill, M. D. Hooven, A. E. Knowlton, C. S. Purnell, C. C. Whipple, and R. J. Wiseman.

The smoker committee consisted of W. R. Van Steenburgh, *chairman;* C. F. Bolles, A. J. Cooper, T. C. Duncan, H. E. Farrer, J. B. Harris, C. T. Hatcher, E. B. King, William Jordan, E. G. D. Paterson, W. H. Rodgers, H. B. Snow, D. W. Taylor, and E. F. Thrall.

The theater- and broadcast-tickets committee included C. S. Purnell, *chairman;* G. H. Campbell, G. J. Dyktor, H. H. Heins, J. P. Neubauer, and T. J. Talley, 3rd.

Analysis of Registration at Recent Winter Technical Meetings

District	1942	1943	1944	1945
New York and foreign (3)	549	569	608	704
Middle Eastern (2)	349	417	474	463
North Eastern (1)	237	254	301	278
Great Lakes (5)	93	97	131	153
Southern (4)	68	22	80	40
Canada (10)	11	25	29	41
South West (7)	9	17	21	32
North West (9)	2	6	6	3
North Central (6)	7	6	4	1
Pacific (8)	6	6	4	3
Totals	1,331	1,419	1,658	1,718

Analysis of Registration at 1945 Winter Technical Meeting

Classification	Dist. 3	Dist. 1	Dist. 2	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	570	242	396	34	127	1	27	1	3	30		1,431
Men guests	107	26	45	4	20		5	2		9	4	222
Women guests	6	6	12	2	6					2		34
Student members	17	4	10									31
	700	278	463	40	153	1	32	3	3	41	4	1,718

Research and the War Theme of General-Session Address

An address, "Research and Its Effect on Winning the War," high-lighted the general session of the 1945 AIEE winter technical meeting. It was delivered by J. Carlton Ward, Jr., president and director, Fairchild Engine and Airplane Corporation, New York, N. Y. Other features of the session were the presentation of a certificate of Honorary Membership to Past President Dugald C. Jackson, professor emeritus of electrical engineering at Massachusetts Institute of Technology, Cambridge, and the presentation of the Alfred Noble prize to W. R. Wilson (A '43), engineer's assistant, General Electric Company, Pittsfield, Mass. President C. A. Powel presided.

Drawing a distinction between research and development, Mr. Ward said that the field of research in the aircraft industry is exemplified by the work of the National Advisory Committee on Aeronautics. Related to research and development, is a third process, the formulation of technical specifications and evaluation, which Mr. Ward characterized as being predominantly a Government function.

Calling attention to the many and sometimes overlapping research agencies established to perform wartime functions, Mr. Ward discussed the current proposal to establish a national research committee to replace the many wartime agencies after the war. He also called attention to the current testimony before the Woodrum committee of the House of Representatives, declaring that not until 1944 has this great nation had in its legislative halls a single committee to formulate a top over-all policy on national defense. The question of what our postwar policy should be on research and development and other aspects of the problem are being debated.

Citing the development of military aircraft as an example, Mr. Ward told how research and development programs that in peacetime would take many years are telescoped into a matter of months during wartime. He closed his address with a discussion of the contributions of electrical engineers and the electrical industry to military aircraft and suggested some of the additional needed developments that electrical engineers might contribute. The essential substance of this address is scheduled for publication in an early issue.

D. C. JACKSON—HONORARY MEMBER

In presenting the certificate of Honorary Membership to Doctor Jackson, President Powel mentioned some of the outstanding men who have been so honored in the past, characterizing Honorary Membership as the highest honor within the Institute's power to bestow. He also called attention to Doctor Jackson's distinguished career as engineering educator and consulting engineer (*EE, Dec '44, p 449*). "Honors of this kind are always exciting," declared Doctor Jackson in his brief response; "the deep sense of appreciation of such recognition enlarges with the

years." Doctor Jackson declared that his feelings were embraced in the whole sentiment expressed by Henry Thoreau when he remarked: "If one advances confidently in the direction of his dreams and endeavors to live the life that he has imagined, he will meet with a success unexpected in common hours."

NOBLE PRIZE TO W. R. WILSON

Established for the encouragement of young engineers, the Alfred Noble prize is awarded annually to a member of one of the four national societies of civil, mining and metallurgical, mechanical, or electrical engineers, or the Western Society of Engineers. It is awarded for the best paper presented during the year by a member of one of those societies who was not over 30 years of age when his paper was published. Mr. Wilson, who received the current award for his paper, "Corona in Aircraft Electric Systems as a Function of Altitude," (*EE, Apr '44, Trans pp 189–94*), is only 25 years of age. The award consists of a certificate and a cash prize currently amounting to $300. Professor James K. Finch of Columbia University, member and past chairman of the award committee, presented the prize to Mr. Wilson. He briefly outlined the history of the prize and some of the principal achievements of Alfred Noble who was an outstanding bridge and tunnel engineer and past president of the American Society of Civil Engineers. The prize was established in 1929 and Mr. Wilson is the seventh AIEE member to receive it.

TRIBUTES TO SCOTT AND LINCOLN

In his introductory remarks, President Powel paid tribute to the late Past Presidents Charles F. Scott and Paul M. Lincoln, who died during December 1944 (*EE, Jan '45, p 41; Feb '45, p 76*). He called attention to the fact that their careers were curiously similar. Both graduated from Ohio State University; both started their life work with the Westinghouse Electric and Manufacturing Company; and both finished as heads of great electrical departments of great schools. He also mentioned the fact that it was Doctor Scott's advocacy of a headquarters building for the Founder Societies that lead Andrew Carnegie to provide a gift that made possible the erection of the Engineering Societies Building. (During winter-meeting week the Institute's board of directors passed resolutions to the memories of both men, which are published elsewhere in this issue.)

Edison Medal Presented at Joint AIEE–IRE Session

Following the custom of recent years, a joint evening session was held during the recent AIEE winter technical meeting with the Institute of Radio Engineers which was meeting concurrently in New York. During the first portion of the two-part program the 1944 Edison Medal was presented to E. F. W. Alexanderson (F '20) consulting engineer, General Electric Company, Schenectady, N. Y., for "his outstanding inventions and developments in the radio, transportation, marine, and power fields." In addition to being a long-time member of AIEE, Doctor Alexanderson is a member and past president of the Institute of Radio Engineers. During the second portion of the program, an address "The Navy Electronics Program and Some

John Grotzinger (A '24) Goodyear Tire and Rubber Company, Akron, Ohio, chairman of the committee on industrial power applications who presided at several technical sessions, discusses the program with Herbert Speight (M '21) Westinghouse Electric and Manufacturing Company, New York, N. Y., former committee chairman

of Its Past, Present, and Future Problems," was delivered by Captain J. B. Dow of the United States Navy, Washington, D. C. AIEE President C. A. Powel presided over the first portion of the program; IRE President H. M. Turner (M '20) over the second.

Preceding the award of the medal, Chairman Karl T. Compton of the Edison Medal committee outlined the history of the medal and R. C. Muir, long-time associate of Doctor Alexanderson, spoke on the human side of the medalist that is not so well known.

Doctor Compton told how a group of friends and associates of Edison established the medal at the turn of the century to commemorate the great inventer's contributions. Funds for a memorial were raised from many contributors, and, following a period of several years of uncertainty with regard to the best form the memorial should take, the plan of awarding an annual gold medal was adopted in 1908. Beginning in 1909, the medal has been presented every year except two. It is awarded by a committee consisting of 24 members for "meritorious achievement in electrical science, electrical engineering, or the electrical arts."

In his talk, Doctor Muir stressed the medalist's love of people, especially young people who work with him. Quoting Doctor Alexanderson's own statement that: "The relationship between the older and younger generations should be one which is not characterized as boss and assistant, but one of teamwork where the younger generation supplies the knowledge in latest techuical development, and the older generation contributes experience and imagination," Doctor Muir added his own observation that "he carries out these principles whole-heartedly."

In his response after President Powel had presented the medal and certificate to him, Doctor Alexanderson paid tribute to Edison as a symbol of American inventiveness that still stands out alone. He told how more than 40 years ago he had emigrated from Sweden to America, attracted by the fame of such names of Edison and Steinmetz and how he found all that he had hoped for in inspiration, opportunity, and friendly guidance. Devoting the major part of his address to invention, he predicted that during the postwar years: "Invention will not solve all our social problems, but it will be a major factor as it has been in the past."

The essential substance of these addresses is scheduled for presentation in an early issue.

THE NAVY'S ELECTRONIC PROGRAM

To indicate the magnitude of the Navy's electronic program, Captain J. B. Dow, in his address following the Edison Medal presentation, said that during the calendar year 1944 more than $1,300,000,000 worth of radio, radar, and sonar equipment was delivered to the Navy, exclusive of the large amount of equipment purchased directly from the Army. He reported also that for the fiscal year 1945 a total of approximately $80,000,000 has been appropriated by the Navy for research and development in the electronic field. The intensity of wartime research in electronics has advanced the art by many years, he said, and, from such observations as we have been able to make, American science and industry have met our needs as well as the Germans have met theirs, and considerably better than the Japanese. He cautioned, however, that we must at least maintain our present position; and to shorten the war, we must improve it.

Calling attention to the importance of the work already done in standardization of component parts of electronic equipment, Captain Dow outlined the great amount of work still to be done in this field and indicated some of the problems still to be solved. "The production of dependable and easily maintained equipments with the least component complexity is greatly contingent upon the early selection and application by the equipment-design engineer of standard approved items for the various required components during the conception, research, and development phases," he declared, adding that, while the prime effort must be directed toward immediate war problems, it is also important that plans for postwar standardization programs be begun.

Captain Dow devoted the concluding part of his address to a discussion of some of the problems that may arise in the postwar development of radar and a proposed pool of radar patents to overcome some of those difficulties. An article embracing the major portion of his address appears elsewhere in this issue.

Publication of Papers to Continue During Ban on Meetings

Although no AIEE national nor District meetings may be held in the near future because of the current wartime restrictions, publication of technical papers and discussions will continue as previously planned, insofar as they are available. Therefore, members intending to write papers for presentation should proceed with the preparation of their manuscripts and submit them to Institute headquarters as soon as completed, just as they would have done if the meetings were to be held. Likewise, those wishing to discuss papers should prepare their discussions in written form and, instead of taking them to the meetings for oral pres-

entation, should mail them to headquarters.

According to present plans, abstracts of papers available in pamphlet form for general distribution will be published in *Electrical Engineering*, as heretofore (the next group of abstracts is scheduled for the April issue). Those wishing to discuss the papers should obtain pamphlet copies from Institute headquarters and submit their written discussions as soon thereafter as possible. Both paper and discussion manuscripts should be addressed to the attention of the secretary of the technical program committee, as usual.

Cancellation of the meetings requires no change in publication policy, and therefore the publication of papers and discussions will continue as before. Technical papers will be published in the Transactions sections of the monthly issues of *Electrical Engineering* insofar as budget limitations and wartime restrictions on the use of paper permit; papers for which space is not available in the monthly issues, plus all approved discussions, will be published in the two semiannual "Supplements to Electrical Engineering—Transactions Section." All approved technical papers and discussions will be published in the *Transactions* volume as in the past.

Industrial Voltage Ratings Discussed in Conference

Points of view of the equipment manufacturers and users and of the power companies in regard to industrial-system and apparatus voltage ratings were thoroughly aired at one of the conferences held during the recent AIEE winter meeting. The conference was one of several sessions and conferences sponsored by the committee on industrial power applications, and John Grotzinger (A '24), chairman of that committee, presided.

The voltage-standardization work being conducted jointly by the Edison Electric Institute and National Electrical Manufacturers Association was summarized by H. P. Seelye (F '43) of The Detroit (Mich.) Edison Company. One of the purposes of that joint study, he said, is to set up operating-voltage variations within which the power industry now is operating or can be expected to operate. He emphasized that well-regulated systems should not and do not have spreads as great as plus or minus 10 per cent.

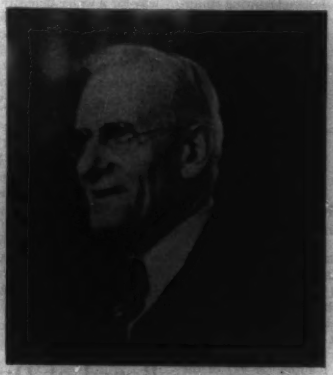
T. C. Duncan (A '30) of the Consolidated Edison Company of New York said that that company supplies service at 120–208 volts to all customers; those requiring different voltages must provide the necessary conversion equipment. In large installations within network areas, the secondary network is run into the customer's premises.

The importance of voltage regulation in modern industrial systems was stressed by D. L. Beeman (M '43) of the General Electric Company, Schenectady, N. Y. He described the characteristics of different plant layouts, and discussed allowable voltage deviations from the standpoint of the equipment manufacturer.

Various aspects of the subject from the point of view of the equipment user were presented by F. W. Cramer (M '40) Carnegie-Illinois Steel Corporation; R. T. Woodruff, Aluminum Ore Company; K. K. Falk, Bendix Aviation Corp.; and John M. Webb (A '35) Eli Lilly Company. In the absence of Messrs. Falk and Webb, Chairman Grot-

In Memoriam

CHARLES FELTON SCOTT



THE directors of the American Institute of Electrical Engineers record with profound sorrow the death of Charles Felton Scott, president of the Institute in 1902–03, Edison Medalist in 1929, and widely honored for his leadership in the engineering profession. He was born at Athens, Ohio, on September 19, 1864, and attended Ohio State and Johns Hopkins Universities, receiving the bachelor of arts degree from the former in 1885. Early in his career he became associated with the Westinghouse Electric and Manufacturing Company and contributed notably to that company's pioneer developments in a-c power and machinery and to its leadership in educational activities. He continued with the Westinghouse company as consulting engineer until 1911, when he accepted the professorship of electrical engineering at Yale University. Doctor Scott retired from active professorial duties in 1933, but continued until the time of his death his lifelong efforts on behalf of the organized life of the engineering profession.

As president of the Institute in 1902–03, Doctor Scott stimulated Section growth and pioneered in the establishment of Student Branches. His inspiring advocacy of a united-building program for the Founder Societies was largely instrumental in securing from Andrew Carnegie a gift of $1,500,000 for this purpose. Doctor Scott also served as president of the Engineers' Society of Western Pennsylvania in 1904, as chairman of the power-transmission section of the International Electrical Congress at St. Louis in 1904, as president of the Society for the Promotion of Engineering Education in 1921–23, as chairman of the Engineers' Council for Professional Development in 1935, and as president of the National Council of State Boards of Engineering Examiners in 1938.

In addition to the Edison Medal conferred by the Institute in 1929, he was the recipient of the Lamme Medal of the Society for the Promotion of Engineering Education in 1930. During his career he received many academic honors, including the degrees of master of arts, Yale University; doctor of science, University of Pittsburgh; and doctor of engineering, Stevens Institute of Technology.

Resolved: That the board of directors of the American Institute of Electrical Engineers upon behalf of the membership hereby expresses its profound sorrow at Doctor Scott's death and its enduring gratitude for his inspiring leadership of the profession at large.

And be it further resolved that these resolutions be recorded in the minutes and be transmitted to members of his family.—*AIEE Board of Directors, January 25, 1945.*

zinger read their prepared talks. Some of the speakers considered the problem more as one of establishing standard voltage spreads than that of setting up specific voltage ratings. Regulators were considered justified in large plants, and the need for pole-mounted regulators for use near large plants was indicated.

In the discussion that followed, some of the manufacturers representatives called attention to the difficulty of manufacturing equipment to operate satisfactorily over the widest voltage spreads found in practice, and urged that the supply system be designed so as to provide rated voltage and thus permit the equipment to operate at highest efficiency and best performance. All agreed that best results will be achieved through the cooperation of equipment users and manufacturers and the power companies.

Silicones as Electrical Insulation Interests Session

The physical characteristics, dielectric qualities, and behavior under different operating conditions of the various silicones described in two technical papers presented at the session on machinery insulation held January 23, during the winter technical meeting, were subjected to keen discussion. The authors, T. A. Kauppi (A'44) of the Dow Corning Corporation and S. L. Moses (M'44) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. (Organo-Silicon Compounds for Insulating Electric Machines), L. R. Hill, G. L. Moses, and J. De Kiep (M'43) all of the Westinghouse Company (The Application of Silicone Resins to Insulation for Electric Machinery), impressed upon their hearers the fact that much needs to be done and trial installations need to be made before the limitations which must be placed on this new insulation compound are learned. There was general accord on the fact that silicones, if properly applied, will add materially to the operating-temperature range of electric equipment and that designers should find use for the resins in the near future.

The moisture-resistant quality of the new insulation was the feature which particularly interested an officer from the Army Signal Corps and a representative of one of the major oil companies. Superiority in moisture resistance over materials in common use is claimed for the silicones, but it is not applicable on coils already wound with other insulating materials. (*A. M. de Bellis, chairman, AIEE subcommittee on insulation resistance.*)

Diversified Program Session on Instruments and Measurements

The improvement of current-transformer characteristics by the superposition of a harmonic frequency on the core, a new telemetering system based on frequency differences, the study of relay operation by electronic circuits, and a portable high-voltage insulation-testing apparatus were the subjects of papers presented to an audience of more than 125 at the instruments and measurements session held Wednesday afternoon, January 24, during the winter technical meeting.

In the discussion which followed presentation of "Orthomagnetic Bushing Current Transformer for Metering," by A. Boyajian (F'26) and G. Camilli (F'43) of the General Electric Company, Pittsfield, Mass., it was pointed out that the paper represented the application of a theoretical principle to the practical improvement of current-transformer characteristics and the method opened the way for a wider diversity of high ratios without exceeding permissible limits of accuracy. Attention was drawn to the fact that 720 cycles appeared to be the upper frequency which produced favorable results. Participating in the discussion were: F. B. Silsbee (F'42) of the Bureau of Standards, Washington, D. C.; E. C. Wentz (M'42) and C. A. Woods, Jr. (A'37) Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; and Stuart D. Moreton (A'43) General Electric Company, Philadelphia, Pa.

The paper, "A Modulated Frequency System of Telemetering," by H. E. Renfro and A. P. Peterson (A'32) of the Control Corporation, Minneapolis, Minn., was characterized by Perry Borden (M'19) of the Bristol Company, Waterbury, Conn., as a valuable contribution to telemetering, describing as it did a practical operative system involving a new principle in the conversion of instrument indications into frequency. Mr. Borden recalled also that the "Report on Telemetering, Supervisory Control, and Associated Circuits" prepared in 1940 by the subcommittee on telemetering, of which he was chairman, mentioned the use of frequency systems.

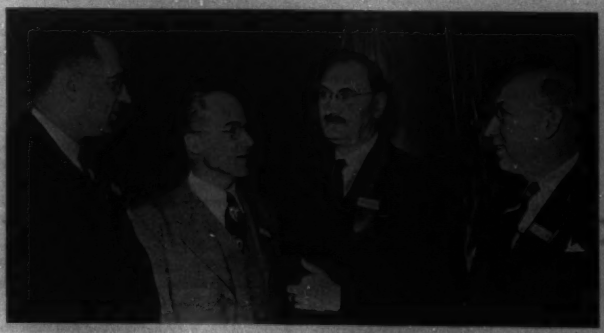
F. W. Atkinson (M'37) and R. B. Taylor, of the TAKK Corporation, Newark, Ohio, authors of "A Portable Instrument for Measuring Insulation Resistance at High Voltage," were congratulated on having devised a new portable apparatus for direct-voltage testing in the field, and the discussers stated that the apparatus also enables the obtaining at high voltage of absorption–current–time characteristics of insulation. The paper was discussed by R. L. Webb (M'35) of the Consolidated Edison Company of New York, Inc., New York; J. S. Johnson (A'36) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; and T. B. Whitson (A'28) of the James G. Biddle Company, Philadelphia, Pa. (*Chester L. Dawes, chairman, AIEE committee on instruments and measurements.*)

Board of Directors Meets During Winter Technical Meeting

The North Eastern District technical meeting scheduled to be held in Buffalo, N. Y., April 25–26, 1945, and the summer technical meeting to be held in Detroit, Mich., June 25–29, 1945, were canceled by the AIEE board of directors at its regular meeting at Institute headquarters, New York, N. Y., January 25. This was in accordance with the decision of the Office of War Mobilization and Reconversion calling for a cessation after February 1 of all group meetings drawing an attendance of over 50 persons using other than local transportation, unless special permission is granted by the War Committee on Conventions who must be convinced that the war effort will suffer if the meeting is not held.

The question of holding the Pacific Coast technical meeting, scheduled for Seattle, in August 1945, was referred to the executive committee for action. The Southern District technical meeting, scheduled to be held in South Carolina in November 1945, was postponed. Decision regarding time and place of the annual business meeting of the Institute was referred to the executive committee with power.

Memorial resolutions were adopted for



A. C. Monteith (M'40) Westinghouse Electric and Manufacturing Company, Director T. G. Le Clair (F'40) Commonwealth Edison Company, President C. A. Powel (F'41) Westinghouse Electric and Manufacturing Company, and C. B. Kelley (M'30) Kansas City Power and Light Company, photographed during the winter technical meeting. Mr. Monteith is chairman of the Standards committee

Past President Charles F. Scott, who died on December 17, 1944, and Past President Paul M. Lincoln, who died on December 20, 1944, as printed elsewhere in this issue.

The board adopted a resolution, offered by the finance committee, which will continue for the year beginning May 1, 1945, the provision that has been in force for several years for an exchange allowance, corresponding to the difference between the New York exchange value and the normal par value of the payment, on payment of membership dues and membership subscriptions to or purchases of Institute publications amounting to two dollars or over, such allowance not to exceed 60 per cent of the bills payable, and to be applicable to the appropriation for each Section in any country affected.

Continuing a policy that has been in effect for two years and otherwise would have expired on January 28, 1945, the board adopted a resolution "that all enrolled Students of the Institute who enter the armed services or the Merchant Marine shall have the option of continuing their Student enrollment during their war service upon payment of the regular annual fee of three dollars, with all publications being sent to their permanent address; or of being inactive Student members, without payment of the fee and without publication service. In either case, enrolled Students will, upon severance from war service, have the same status as if they were then college students or had been graduated from college on that date, depending on whether they continue their education or not—this policy to be in effect for a period of two years."

The board approved recommendations of the Standards committee for the appointment of AIEE representatives as follows:

W. A. Brecht to succeed F. B. Powers as AIEE representative on the Sectional Committee on Railway Motors *C35*, and W. S. H. Hamilton as chairman of this Sectional Committee, succeeding former Chairman F. B. Powers.

Robert D. Evans on the proposed Sectional Committee on Methods of Measuring Radio Noise.

E. M. Callender to replace Wray Dudley, resigned, on Sectional Committee on Electric Welding Apparatus *C52*.

J. E. Hobson to replace R. E. Johnson, resigned, on Sectional Committee on Electric Water Heaters *C72*.

W. L. Heard as chairman of Sectional Committee on Graphical Symbols and Abbreviations for Use on Drawings *Z32*, to succeed H. W. Samson, resigned.

Chairman I. Melville Stein of the AIEE committee on collective bargaining and related matters, present by invitation, presented the report of that committee, dated January 9, 1945. The board approved the report in principle and authorized the committee to publish it. An additional appropriation was granted to the committee toward the cost of preparation of a proposed manual of information on the subject.

Upon recommendation of the vice-president of the Middle Eastern District (number 2), the Toledo and Dayton Sections, and the Sections committee, the board voted to transfer Allen County, Ohio, from the territory of the Toledo Section to that of the Dayton Section.

Proposed amendments to the constitution, authorized by the board of directors on June 29, 1944, and rewritten in a form which has been approved by legal counsel, were reported by the committee on constitution and bylaws, and were approved by the board for sub-

In Memoriam

PAUL MARTYN LINCOLN

PAUL MARTYN LINCOLN, Institute president 1914–15, died on December 20, 1944 at the age of 74. He was born at Norwood, Mich., January 1, 1870, and attended Western Reserve and Ohio State Universities, receiving the mechanical engineer degree in electrical engineering from Ohio State in 1892. Prior to graduation from Ohio State University, he was employed by the Short Electric Company of Cleveland. Immediately after graduation he entered the testing department of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa.

Mr. Lincoln was employed as electrical superintendent in charge of powerhouse operations by the Niagara Falls Power Company from 1895 to 1902. In 1902 he returned to the employ of the Westinghouse Company and for two years worked as an application engineer in the early introduction of the single-phase interurban and main-line railroad electrification. In a reorganization of the engineering department of the Westinghouse Company in 1904, he became power division engineer. In this position he was responsible for the design of large a-c and d-c rotating machinery and switchboards. Mr. Lincoln was appointed a general engineer on electric-power stations and transmission in the general engineering department in 1910 and served in this capacity until 1919. During a part of this same period from 1911 to 1915, he also served as head of the engineering school in the University of Pittsburgh and in connection with this work developed a new type of demand meter. In 1919 Mr. Lincoln resigned from the Westinghouse Company to become consulting engineer for the Lincoln Electric Company of Cleveland, Ohio, and in 1922 he was appointed director of the school of electrical engineering at Cornell University. He served in this capacity until his retirement in 1939.

Mr. Lincoln organized the Lincoln Meter Company, Ltd., of Toronto, Canada, and the Lincoln Meter Company, Inc., of Springfield, Ohio, to develop commercially his demand-meter patents. This work was highly successful in Canada and his type of demand meter became the standard throughout Canada. In 1938 he organized the Therm-Electric Meter Company in Ithaca, N. Y., to develop commercially a new form of thermodemand meter.

Mr. Lincoln was a member of several scientific and engineering societies, and of the board of management of the World's Congress of Engineers (1923–25). In 1902 he received the John Scott Medal Award from the City of Philadelphia upon the recommendation of the Franklin Institute for his invention of the synchroscope.

Mr. Lincoln served the Institute as manager (1906–09); as vice-president (1909–11); and as president (1914–15). He was very active on Institute committees, serving on the papers, and meetings and papers (now technical program) committees; on the executive, Sections, and law committees; and on many technical committees as power stations, protective devices, transmission and distribution, electric machinery, standards, instruments and measurements, Edison and Lamme Medal committees, and the board of award of the John Fritz Medal.

Resolved: That the board of directors of the American Institute of Electrical Engineers upon behalf of the membership hereby expresses sincere appreciation of Mr. Lincoln's many contributions during his membership of 46 years to the development of Institute activities and his service to the engineering profession as a whole and deepest regret at his death.

And be it further resolved that these resolutions be entered in the minutes, and copies be transmitted to members of his family.—*AIEE Board of Directors, January 25, 1945.*

mission to the membership for vote by letter ballot.

Upon recommendation of the committee on constitution and bylaws, amendments to the bylaws were adopted, as follows:

Section 65. In the list of technical committees, the title of the committee on electrical machinery was changed to "committee on electric machinery" (to conform to the American Standard "Definitions of Electrical Terms").

Sections 51–57, 60, 64. Wording changed in accordance with the approval by the board of directors, on June 29, 1944, of a recommendation of the committee on Student Branches for an amendment to the bylaws covering the use of the designation "Student member" instead of "enrolled Student."

T. H. Morgan and I. Melville Stein were reappointed Institute representatives on the council of the American Association for the Advancement of Science for the calendar year 1945.

H. S. Osborne was appointed an AIEE representative on the Hoover Medal board of award for the six-year term beginning in May 1945, to succeed F. M. Farmer, whose term will expire at that time.

The board approved changes in articles *C2* and *C5* of the constitution of the American Standards Association as submitted to the member-bodies of the association under date of December 27, 1944.

Report was made of the following actions on applications by the executive committee as of December 8, 1944: 12 applicants transferred to the grade of Fellow and 31 transferred to the grade of Member; 18 applicants elected to the grade of Member and 100 elected to the grade of Associate; 436 Students were enrolled.

Recommendations of the board of examiners, adopted at meetings on November 16 and December 21, 1944, and January 18, 1945, were approved. Upon recommendation of the board of examiners, the following actions were taken: 8 applicants were transferred to the grade of Fellow; 92 applicants were transferred, 66 were elected, and one was reinstated to the grade of Member; 311 applicants were elected to the grade of Associate; 362 Students were enrolled.

Appropriation expenditures were reported by the finance committee, as follows: $28,473.83 in November 1944, $25,978.92 in December 1944, and $25,566.53 in January 1945.

Those present were:

President—C. A. Powel, East Pittsburgh, Pa.

Past Presidents—N. E. Funk, Philadelphia, Pa.; H. S. Osborne, New York, N. Y.

Vice-Presidents—C. B. Carpenter, Portland, Oreg.; M. S. Coover, Ames, Iowa; J. F. Fairman, New York, N. Y.; J. M. Gaylord, Los Angeles, Calif.; W. J. Gilson, Toronto, Ont.; R. T. Henry, Buffalo, N. Y.; C. W. Ricker, New Orleans, La.; R. W. Warner, Austin, Tex.; W. E. Wickenden, Cleveland, Ohio.

Directors—P. L. Alger, Schenectady, N. Y.; C. M. Laffoon, East Pittsburgh, Pa.; T. G. LeClair, Chicago, Ill.; F. R. Maxwell, Jr., Pensacola, Fla.; M. J. McHenry, Toronto, Ont.; C. W. Mier, Dallas, Tex.; S. M. Mortensen, Milwaukee, Wis.; D. A. Quarles, New York, N. Y.; W. R. Smith, Newark, N. J.

National Secretary—H. H. Henline, New York, N. Y.

Trend Toward High-Speed Relays Seen at Generator Conference

A conference session on generator protection was held as a part of the AIEE winter technical meeting, at which the following three papers were presented by members of the working group on this subject:

"Generator Differential Protection," by W. K. Sonnemann (M '43), Westinghouse Electric and Manufacturing Company, Newark, N. J.

"Generator Protection," by E. L. Michelson (A '37), Commonwealth Edison Company, Chicago, Ill.

"Generator Field Protection," by H. F. Lindemuth (M '41), Consolidated Edison Company of New York, Inc., New York, N. Y.

The session was called to order by W. A. Lewis (M '39), chairman of the relay subcommittee of the AIEE committee on protective devices, who outlined the aims of the subcommittee and the part that these conference sessions played in the development of the committee's program. He then turned the meeting over to J. C. Bowman (A '40).

Mr. Sonnemann's presentation favored simultaneous tripping in case of fault and saw a trend toward one-cycle relays to gain five cycles over the time required with six-cycle relays. The practice of the Commonwealth Edison Company of Chicago, Ill., was reviewed by Mr. Michelson, who indicated that an effort is made to keep the generators on the line as long as possible. The system is such that there is little possibility of having through fault current. He indicated that the company's practice favors operating machines as induction generators in case of loss of field, rather than tripping, provided the time of such operation is not unduly long. Mr. Lindemuth's paper described the insulation of field-protective relays on machines of the Consolidated Edison Company of New York. He pointed out that ten years ago the only field protection installed on this system consisted of two incandescent lamps connected in series across a field circuit with their mid-point grounded. Installations now have been made of undervoltage and undercurrent protection, field-ground indication, and field-temperature indication.

During the discussion following the presentation of the papers, a plea was made for more detailed information on failures, because of the lack of information on damage to machines as related to relay times. Neutral resistance was declared to be of value in reducing iron burning. A view was expressed that generators should be cleared from the system as rapidly as possible in order to minimize damage to the machine, and that the system should be designed for operation with the loss of any unit. Other problems encountered by the various companies represented, together with the solutions of these problems, were described.

The enthusiasm shown by the participants in the discussion indicated that the subject was of vital interest to the industry at large, and that the subject was well chosen for a conference session.

Four Sessions Sponsored on Transmission and Distribution

Three regular technical sessions and one conference session on wartime practices on distribution systems and their effect on system operation and future designs were sponsored at the winter meeting by the committee on power transmission and distribution.

WARTIME PRACTICES

At the conference session, the history of interruptions in the past five years on the system of the Duquesne Light Company, Pittsburgh, Pa., for various kinds of service, was related by E. V. Hill in a paper, "Analysis of Customer-Service Interruptions As a Means of Determining Acceptability of Designs for Methods of Supply." Mr. Hill estimated that 70 per cent of the outages on the Duquesne system occurred on the distribution circuits. The number of outages increased as the transmission voltage decreased, with very few recorded on the company's high-voltage transmission lines.

The changes wrought by wartime stringencies in both system and industrial substation design were described by N. G. Larson (A '35) of the Commonwealth Edison Company, Chicago, Ill., in his paper, "Distribution Substation Design in Chicago as Influenced by Wartime Conditions." Chief among the modifications was the dropping of primary busses from system substations. In some instances bus-voltage regulation was substituted for individual feeder-voltage regulation. Mr. Larson also mentioned the need for economy in future design.

A paper by L. M. Olmsted (M '39) of the Duquesne Light Company studied the "Limiting Effect of Auxiliary Equipment, Such as Connectors and Clamps Upon the Ratings of Overhead Conductors." According to Mr. Olmsted's studies, clearance and connectors do limit the ratings of overhead conductors, particularly suspension clamps. He suggested that suspension and strain clamps be redesigned to reduce magnetic heating. He reported the most satisfactory results with connectors of the twisted-sleeve type and expressed the opinion that compression connectors hold much promise for the future.

E. W. Oesterreich (F '42) of the Duquesne Light Company presented the final paper of the session, "Analysis of Availability of Equipment as Affected by Prearranged Maintenance Requirements and Capacity Limitations Resulting From Equipment Failure."

These papers and the ensuing discussion indicated that some practices adopted as wartime expedients would remain permanently. Others, however, will be replaced, as originally intended, by reversion to former practices or development of improved procedures. E. W. Oesterrich and E. K. Huntington (M '35) presided jointly at the conference.

The technical sessions sponsored by the committee were on cables and corrosion at which R. J. Wiseman (F '27) presided; on lightning and protective relaying and on supervisory control and stability at both of which H. E. Wulfing (M '23) chairman of the committee on power transmission and distribution, presided.

CABLES AND CORROSION

Four papers were presented at the session on cables and corrosion. First of these was paper 45-58, "The Dielectric Strength and Life of Impregnated Paper—IV," by J. B. Whitehead (F '12) and J. M. Kopper, III (A '34), the fourth in a series of papers reporting the results of investigation by Doctor Whitehead and his associates at Johns Hopkins University into the relationship between kind of oil and density of paper on the dielectric strength, power factor, and capacitance of the dielectric—oil-impregnated paper.

Further confirmation was given that the voltage breakdown starts in an oil channel or the gap in the paper tape; also that low-density paper gives a higher breakdown voltage than high-density paper, because the lower specific inductive capacity of low-density paper results in a lower electric stress on the oil channel, and, therefore, a higher voltage is required to break down the oil channel. The paper offers an explanation of the mechanism of voltage breakdown, power factor, and capacitance as related to paper density in terms of fundamental conductance phenomena in insulating oils.

Paper 45-60, "The Galvanic Corrosiveness of Soil Waters," presented by H. S. Phelps (A '21) and F. Kahn (A '36), reported the results of attempts to determine how the *pH* value of soil waters influence the corrosiveness of copper, lead, iron, and carbon when each acts as an anode or cathode. Their findings indicate that galvanic corrosiveness on lead, copper, and iron is generally more severe for low *pH* than for high *pH*. The relationship between static potential of each of the four elements and *pH* and the relationship between the polarization potential of each of the four elements and *pH* are given.

C. M. Sherer (A '39) and K. J. Granbois (A '31) in paper 45-61, "Study of Alternating Sheath Currents and Their Effect on Lead-Cable Sheath Corrosion," reported on an investigation conducted by the Safe Harbor Water Power Corporation as a result of cable-sheath failures which appeared to be caused by a-c electrolysis. A description of the conditions present when failures occurred and the laboratory studies carried out to duplicate the sheath corrosion is given in the paper. The authors concluded that the cable failures were the result of rectified induced alternating sheath currents in combination with galvanic currents plus possibly a small amount of chemical action. It was suggested that in new installations of single-conductor lead cables in underground-duct systems caution be observed to guard against the effect of water seeping into the ducts. A warning was given regarding the use of laboratory data to explain field results on a time basis.

Paper 45-59, "Electrolysis and Corrosion of Underground Power-System Cables," which was presented by L. J. Gorman, gave a very complete yet concise review of the causes for electrolytic corrosion and galvanic corrosion (as distinguished from corrosion from currents flowing from the metallic sheath), chemical corrosion, the results of surveys which show the relationship between duct resistance and rate of cable failure and suggested methods for reducing the number of cable failures by electrolysis mitigation, cathodic protection, protective coverings over the cable and the practices of coating the cable with grease and flushing ducts.

LIGHTNING AND PROTECTIVE RELAYING

The three papers presented at the session on lightning and protective relaying roused a lively discussion.

Paper 45-67, "Impedances Seen by Relays During Power Swings With and Without Faults," by Edith Clarke (M '33) presented a simple method of constructing charts of the system impedances seen by distance relays during power swings. These charts provide a simple means for determining the setting of distance relays. Power swings during all types of unsymmetrical faults, as well as during symmetrical system conditions, were considered. The paper was discussed by L. F. Kennedy (M '39) and A. R. van C. Warrington (A '31) General Electric Company, Schenectady, N. Y.; E. W. Kimbark (M '35) Northwestern University, Evanston, Ill.; F. C. Poage (M '38) Ebasco Services, Inc., New York, N. Y.; and E. L. Michelson (A '37) Commonwealth Edison Company, Chicago, Ill.

Paper 45-18, "Lightning Investigation of 132-Kv System of American Gas and Electric Company," by I. W. Gross (M '40) and G. D. Lippert (A '38) presented data on lightning conditions at major stations in relation to the number of disturbances, lightning currents, attenuation, effect on multiple lines, rate of voltage change, improvements of ground wires, and other factors. The paper was discussed by J. H. Hagenguth (A '28) General Electric Company, Pittsfield, Mass., and P. L. Bellaschi (F '40) Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Paper 45-26, "Lightning Investigation on Transmission Lines—VIII," by W. W. Lewis (F '38) and C. M. Foust (M '31) continued the lightning investigations of the authors and presented data relating to rate change of voltage, maximum voltage and current in ground wires and arresters. The paper was discussed by J. H. Hagenguth and E. D. Sunde (A '36) Bell Telephone Laboratories, Inc., New York, N. Y.

SUPERVISORY CONTROL AND STABILITY

The third session consisted of four papers. Paper 45-77, "The Combination of Supervisory Control With Other Functions on Power-Line Carrier Channels," by R. C. Cheek (A '42) and W. A. Derr (A '43) outlined the conditions that must be satisfied for proper operation of the standard supervisory control system, and explained difficulties and methods of co-ordinating supervisory with other functions of power-line carrier channels.

Paper 45-7, "Supervisory Control for New Chicago Subway," by W. A. Derr (A '43), C. J. Buck, and J. A. Stoos, described the Visicode supervisory control equipment used to control power for the subway and designed to furnish all necessary information to the dispatchers in as small a space as feasible. The paper was discussed by C. E. Parks (A '40) Public Service Company of Indiana, Indianapolis.

J. E. Housley (F '43) Aluminum Company of America, Alcoa, Tenn., H. B. Wolf (M '37) Duke Power Company, Charlotte, N. C., and J. H. Lampe (M '26) University of Connecticut, Storrs, in the lobby between sessions. Mr. Housley is a past AIEE director, and chairman of the committee on electrochemistry and electrometallurgy

Paper 45-78, "Power-Line Carrier Channels," M. J. Brown (M '44) discussed the attenuation of high-frequency currents in power-line carrier channels on the basis of theory and practical measurements. The paper was discussed by R. N. Stoddard (M '34), Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

Paper 45-13, "Improving Stability by Rapid Closing of Bus-Tie Switches," by E. W. Kimbark, outlined calculations showing that stability could be increased on high-voltage transmission systems under certain conditions by closing high-voltage bus-tie breakers simultaneously with the opening of the circuit breakers on the faulty lines. The paper was discussed by E. L. Michelson (A '37) Commonwealth Edison Company, C. E. Parks, and E. K. Huntington, Rochester (N. Y.) Gas and Electric Corporation. (*H. E. Wulfing, chairman, AIEE committee on power transmission and distribution.*)

Power-Station Auxiliaries Discussed at Conference Session

A conference was held during the AIEE winter technical meeting for the purpose of obtaining an informal cross section of existing practice in the supply of power for auxiliaries in steam-electric stations. A. J. Krupy (M '33) chairman of the committee on power generation presided.

The conference consisted of the presentation of a number of prepared papers, followed by a period for discussion. The first paper, by J. B. McClure (A '29) and Hal Gibson of the General Electric Company, Schenectady, N. Y., was intended to suggest how standard equipment may be used in the modern power plant to provide a satisfactory auxiliary power system. The following general conclusions of the authors were presented as a guide in planning a system:

1. Individual power supply for each boiler should be considered.
2. Power supply from generator terminals is being increasingly used.
3. The preferred system voltages are 460 and 2,400 volts.
4. It is economical to use 460 volts for transformer capacities up to and including 1,000 kva.
5. Dual-voltage systems using 2,400 and 460 volts should be considered for transformer capacities of 1,500 kva and up.
6. In the dual-voltage system, motors up to 200-250 horsepower can be operated economically at 460 volts.

The modern trend toward all-electric drives for auxiliaries was reviewed in a paper by W. R. Brownlee (M '38) and J. A. Elzi (M '38) of the Commonwealth and Southern Corporation, Jackson, Mich., who reached the following conclusions:

1. Experience over a number of years, including that with 500,000 kw of modern 850-pound 900-degree steam plants, has demonstrated the reliability and economy (both first cost and operation) of a station power system supplied from transformers rather than from house turbines or shaft generators.
2. In the unit system of plant arrangement, it is advantageous to connect station power transformers at generator voltage, so as to provide a natural cushion against transmission-system faults. However, this is not so necessary, if faults on the transmission system are cleared with modern relay and breaker speeds and the control system is properly co-ordinated.
3. The use of intermittent-running automatic-starting constant-speed motors for certain applications and variable-speed couplings for others results in the use of line-

starting squirrel-cage induction motors for practically all drives, with important advantages in reliability, simplicity, flexibility, and convenience in operation.

4. Careful analysis of drive characteristics and comprehensive performance tests has resulted in the use of inexpensive control and switching equipment for the many noncritical auxiliaries, with more costly equipment limited to a few essential applications.

5. The problem of protecting motors and circuits in a central station differs from the typical industrial application, since in the former the proper co-ordination of motors with drive characteristics, maintenance on a program basis, and close surveillance by station operators of equipment and its performance eliminates many causes of motor failures. Accordingly, in central stations, schemes of protection should emphasize continuity of service.

Distribution systems, motors, and switchgear, for central-station auxiliaries were the subjects high-lighted in a paper by H. N. Muller, Jr. (M '43) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. With reference to a network system for supplying power to auxiliaries, he indicated that the advantages of reliability, flexibility, and simplicity of this type may be obtained at less cost than a radial system of comparable reliability. The use of squirrel-cage motors with full-voltage starting wherever possible was recommended. The requirements of reliability in switchgear were held to be met best by metal-enclosed equipment.

Auxiliary power supply in the Southwark station of the Philadelphia (Pa.) Electric Company was described in a paper by J. H. Harlow (M '43). This station is now under construction, and will comprise a 150,000-kw 0.8-power-factor cross-compound hydrogen-cooled turbogenerator, two 850,000-pound-per-hour open-pass boilers, and the necessary complement of auxiliaries. A future second unit is contemplated. As a result of certain known factors and experiences, the plan adopted comprises an auxiliary turbogenerator for each main unit of sufficient capacity to drive the essential main-turbine and boiler auxiliaries. Each auxiliary unit will supply two 4,000-volt auxiliary bus sections. To each of these bus sections all of the auxiliaries for one boiler and about one half of the auxiliaries for the main unit will be connected. Station-service auxiliaries and lighting will be connected to two 4,000-volt station-service bus sections which will be supplied through transformers from the main station 13.2-kv bus. Provision will be made for connecting the station-service bus sections with the auxiliary-generator bus sections so that power will be available during outages of the auxiliary generator. These connections will not be closed under normal conditions.

The design of auxiliary power supply on the system of the Commonwealth Edison Company was presented in a paper by V. E. McCallum (M '38). He summarized five essentials for the main characteristics of the auxiliary power supply of a generating station, where auxiliaries are driven by motors, as follows:

1. A separate and independent auxiliary supply unit will be set up for approximately 100,000 kw of generating capacity.

2. The auxiliary power service units will be fed from the main station busses.

3. Each auxiliary power center is to be supplied by two lines operating in parallel, one line connected to the bus supported by the generating unit and one line for the reserve transformer from the bus on an opposite system supported by a transmission line.

4. All contactors, circuit breakers, relays, and control apparatus are to be installed in separate well-ventilated rooms.

5. For simplicity, it is recommended that two voltages be employed and the services to all motors be standard and have the same method of operation.

After the presentation of the prepared papers, 12 discussions were presented from the floor, the salient features of which follow:

1. Where space is at a premium the space requirement for switchgear may become a very important element, and the same would apply to space requirement for conduit. If electric distribution could be simplified along the lines of steam distribution by the elimination of multiple circuits, a considerable reduction in first cost could be effected.

2. Another method of cost reduction could be had by tying more than one motor on a single circuit breaker.

3. Where the choice lies among a house generator, shaft generator, or transformer for supply, the transformer offers the lowest cost. However, it is contended that the higher cost for the house generator is justified by its better reliability.

4. A suggestion was made that studies be undertaken to determine how much frequency can be reduced before loss of motors occurs.

5. One company reported trouble with fly-ash deposits on induced-draft fan motors.

6. With reference to space requirement it was pointed out that on one hydroelectric system in Canada, two 8,000-kw house turbogenerators occupy the same space as a 40,000-kw unit.

7. There appears to be no justification for providing low-voltage protection with time-delay relaying for motors operated at less than 2,300 volts.

8. It was suggested that more thought be given to the minimum size motor that can be justified for operation at 2,300 volts.

9. The merits of grounded and ungrounded systems should receive more study.

(*A. J. Krupy, chairman, AIEE committee on power generation*)

Vice-President J. F. Fairman (F '35) Consolidated Edison Company of New York, Inc., New York, Tomlinson Fort, Jr. (M '35) Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and Vice-President R. T. Heary (F '33) Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y., find F. S. Brown (M '27) Duquesne Light Company, Pittsburgh, Pa., to be an attentive listener. Mr. Fairman was chairman of the winter technical meeting committee, and Mr. Brown presided at the session on electric machinery

Diverse Subjects on Power-Generation Program

At the session on power generation held January 22, four papers on nonrelated subjects were presented and were followed by 14 discussions. Brief summaries of each paper and the related discussions follow.

The paper, "Evaluation of Electric-Distribution Losses in Terms of Generating-Station-Capacity Investment," was presented by Mario Mortara, consulting engineer. His paper reduced to mathematical terms the procedure normally followed in evaluating distribution losses in terms of required investment of generating capacity. The paper was not intended to apply to high-voltage-transmission-line losses. The general consensus was that the paper is a valuable and interesting contribution to engineers concerned with the design of distribution systems, since it clearly sets forth the underlying principles for evaluating alternate schemes based on long-time trends. Some criticism was made of the title of the paper for not indicating that the paper deals with power losses as distinguished from energy losses. It was suggested that the evaluation should be made on the basis of average losses instead of peak-power losses, since the losses vary considerably during the peak period of the daily load cycle. Some discrepancies in the derivation of equations 12 and 13 of the paper were pointed out.

H. C. Marcroft (A '31) of the Pennsylvania Water and Power Company, Baltimore, Md., presented: "Use of Dielectric-Absorption Tests in Drying Out Large Generators," in which he described a method for utilizing the dielectric absorption of generator-winding insulation to indicate when full operating voltage may be applied with safety. The method, with some modifications, has been in use on several electric systems for about two

years with all-around satisfactory results. It was stated that, in view of the general agreement that the procedure described by Mr. Marcroft was an improvement in the technique previously employed, the paper should be of considerable value to those concerned with the problem of moisture removal from generator-winding insulation. Direct voltage of 500, 1,000, or 1,500 volts supplied from a storage battery, which it is claimed is preferable to available mechanical, chemical, or electric rectifiers, was used. On some systems, direct voltages up to 1,500 volts are employed.

The paper, "Frequency Changers—Characteristics, Applications, and Economics," was presented by S. B. Crary (M '37) and R. M. Easley of the General Electric Company, Schenectady, N. Y.

A paper of the AIEE—ASME Joint Committee on Turbogenerators, "Proposed Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing Turbogenerators," was presented by M. S. Oldacre (M'42) of the Commonwealth Edison Company, Chicago, Ill., who was chairman of the group representing AIEE. The proposed preferred standards for the generator are based on replies to a questionnaire submitted to many operating companies, and they represent the majority viewpoint. It was emphasized that the proposed standards may not meet the requirements of all systems, and are not intended to preclude a modification of the standards when required. The primary justification for establishing preferred standards is the reduction in cost and time for delivery, and it is obvious that the purchaser of a nonstandard machine will lose these benefits.

The preferred standards have been submitted to the AIEE board of directors by the Standards committee with the recommendation of approval for a trial period of one year, which will allow ample time for consideration of any modifications which may be submitted during this period.

Suggestions submitted for consideration were:

1. Specification of pull-out torque.

2. Specification of maximum capability when the generator is operated without hydrogen cooling.

3. Too much emphasis has been placed on the inclusion of pilot exciters. Many systems operate units without pilot exciters, and the question arises whether pilot exciters should be specified as standard equipment.

4. A plea was made for the preparation of preferred standards for units rated under 10,000 kw to meet the requirements of designers of power supply for industrial users.

(*A. J. Krupy, chairman, AIEE committee on power generation.*)

Conference Plans to Resolve D-C Temperature-Data Conflict

A proposal for the revision of American Standard C50, presentation of data on the stray-load loss in d-c machines, and submission of a proposed testing code for carbon brushes comprised the agenda of the conference on temperature measurement of d-c machines, held January 23 during the winter technical meeting.

The proposal for the revision of Table I in the American Standard to cover short-time-rated machines and temperature measurement by the resistance method came from T. M. Linville (M '34) of the General Electric Company, Schenectady, N. Y. However, it was agreed, because of conflicting data on a suitable differential in temperature rise between the thermometer and resistance, that it would be desirable to interchange some motors and secure data on several motors in several laboratories. The motor size for these experiments should be 10 to 25 horsepower, and anyone desiring to participate in the experiments should communicate with W. R. Hough (M '41) of the Reliance Electric and Engineering Company, Cleveland, Ohio.

C. M. Dodd, Ames, Iowa, who is chairman of the promotion and development committee of the Institute of Ceramic Engineers, with A. J. Krupy (M '33) Commonwealth Edison Company, Chicago, Ill., chairman of the committee on power generation, who presided at several technical sessions

E. R. Summers (A '38) and L. H. Stauffer (M '43) of the General Electric Company, Schenectady, N. Y., presented a proposed testing code for carbon brushes and an account of their experience with such testing. Dimiter Ramadanoff (M '37) of the National Carbon Company, Cleveland, Ohio, outlined some of the difficulties encountered in this testing. The conferees decided that the proposed code be referred to the committee on electric machinery with the recommendation that a joint subcommittee of that committee and the committee on air transportation consider the proposal. (*W. R. Hough, chairman, AIEE d-c machinery subcommittee.*)

Conference on High-Frequency Dielectric Heating

The conference on high-frequency dielectric heating, presided over by J. J. Orr (A '30) of the committee on industrial power applications attracted a larger attendance than many technical sessions. The first paper presented, by C. J. Madsen (M '44) Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., reviewed the advancement and use of dielectric heating.

The second paper presented at the conference was by T. W. Scott, Jr., Armstrong Cork Company. He discussed the determination of the practical upper limit for frequencies for heating with the object of selecting frequency bands for use during the period of the next few years. By the establishment of such bands, co-ordination between the users and suppliers of equipment could be facilitated.

An experimental use of dielectric heating in the curing of sponge rubber was described by E. L. Bailey (F '43) of the Chrysler Corporation, Highland Park, Mich., who said the curing time had been reduced from as much as three hours to about three minutes. For this application, specially designed electrodes were used with glass molds to serve as restraining forms. Contrary to the usual practice of curing rubber in a mold, the temperature of the container is never higher than that of the charge.

Discussion followed the presentation of the three papers and was concerned largely with the problem of voltage measurement. P. L. Bellaschi (F '40) Westinghouse Electric and Manufacturing Company, Sharon, Pa., compared the present status to that which prevailed in 1934 on impulse voltage and current measurement. He advocated the expansion of AIEE Standard 4 by the extension of frequency limits.

At the end of the discussion period, a report of the Federal Communications Commission which covered frequencies for heating, medical, and scientific uses was read, with particular reference to its application in the field of high-frequency dielectric heating. It was indicated that the narrow frequency bands assigned for this use would require excellent frequency control and stability, which would lead to the use of crystal-controlled oscillators. A proposal was made by H. C. Gillespie of the RCA Victor Division of the Radio Corporation of America, that the power rating of equipment be expressed in Btu per hour in order that there may be a common ground for users and manufacturers.

Educational Program Planned at Conference on Statistical Methods

Plans for an educational program to include a series of articles in *Electrical Engineering* was one of the important outgrowths of the conference on statistical applications held during the AIEE 1945 winter meeting. The first article in the series is tentatively scheduled to appear in the April issue. The conference was sponsored by the joint committee for development of statistical applications in engineering and manufacturing. Purpose of the conference was to give information on the principles of statistical analysis as applied to quality control and to describe several applications with a view to arousing interest and promoting study of applications in the electrical field. W. P. Dobson (F '43), chairman of the joint committee, presided.

Four papers were presented dealing with: statistical tools for controlling quality; statistical methods applied to insulator development and manufacture; application of quality control to resistance welding; and the demerit schedules of Underwriters' Laboratories. These were followed by a comprehensive discussion.

Several speakers stressed the lack of knowledge among engineers of the technique of statistical applications and suggested that the subcommittee undertake an educational program. Several applications in war industries, in addition to those treated in the papers, were described. Information was furnished regarding intensive short courses available to Institute members. The discussion also covered the interest of the purchaser and his relation to the manufacturer, and the possible savings in inspection costs by the application of statistical methods.

In view of the interest of the Government

and industry in the expansion of standards in the consumer-goods field, it was suggested by several that the application of statistical methods of quality control would be an important factor in labeling and certification programs. Test procedures should be worked out and laboratory facilities provided for making tests. The value of the statistical viewpoint in relation to problems in economy was pointed out.

Those taking part in the discussion included: J. Manuele and Casper Goffman, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.; P. L. Alger (F'30) General Electric Company, Schenectady, N. Y.; H. F. Dodge, Bell Telephone Laboratories, New York, N. Y.; M. M. Brandon (M'36) Underwriters' Laboratories, Inc., New York, N. Y.; A. I. Peterson (A'23) New York University, N. Y.; L. S. Hobson (M'39) and R. S. Inglis, General Electric Company, Philadelphia, Pa.; J. J. Taylor (A'37) Ohio Brass Company, Barberton, Ohio; C. B. Brown (A'37) Naval Ordnance Laboratory, Washington, D. C.; R. L. McCoy (M'43) Locke Insulator Corp., Baltimore, Md.; and Professor Grant. (*W. P. Dobson, committee chairman.*)

Army–Navy Group Co-operates in High-Frequency Conference

An all-day conference session on high-frequency cables under the sponsorship of the AIEE committee on communication with the co-operation of the Army–Navy Radio-Frequency Cable Co-ordinating Committee was held January 26. Lieutenant Commander John H. Neher (M'38) United States Naval Reserve, presided.

An outline by Commander Neher of the development of radio-frequency cables from the time of the United States's entry into the war until the present briefly introduced the general subject and explained the establishment of the Army–Navy Radio-Frequency Cable Co-ordinating Committee, its functions, and what it has accomplished.

The characteristics of polyethylene used as the dielectric in radio-frequency cables were discussed under the leadership of W. J. Clarke of the Bell Telephone Laboratories, Inc., New York, N. Y. The general characteristics of the material were presented by J. W. Shackelton of E. I. Dupont de Nemours Corporation; its use as cable insulation by A. E. Maibauer of the Bakelite Corporation; and its dielectric strength by Wm. A. Del Mar (F'20) of the Phelps-Dodge Copper Products Corporation, Yonkers, N. Y.

Mr. Clarke explained the difference between the various grades of the British product and that manufactured in the United States and compared the properties of several samples of polyethylene from different sources.

T. M. Odarenko (M'42) of the Federal Telephone and Radio Corporation, New York, N. Y. presented a discussion on radio-frequency cable manufacture.

The discussion on cable design, which was led by J. F. Wentz (M'42) of Bell Laboratories included a general statement by him of the design considerations involved; and remarks on power ratings and stability by M. C. Bakeborn (A'32) of the Bell Laboratories, a discussion on shielding characteristics of the cables by R. G. Fluharty of the Radiation Laboratory, and a consideration of losses in components by G. L. Ragen of the Radiation Laboratory.

Dixon Lewis (M'38) Aluminum Company of America, and F. W. Linder (A'41), Rural Electrification Administration St. Louis, Mo., author of a paper presented at the protective-devices session

E. E. Sheldon (M'43) of the General Electric Company, Bridgeport, Conn., presented a summary of the types of radio-frequency cables now included in the "Army–Navy Standard List of Cables and Specifications."

The final subject, cable testing, was introduced by J. M. Miller of the Naval Research Laboratory who discussed the standard electrical and mechanical tests required by the armed services. This was followed by discussions on electrical tests over a wide range in frequencies by C. C. Fleming of Bell Laboratories; measurements at relatively low frequencies, using a special method by C. Stewart, Jr., of the Aircraft Radio Laboratory; and measurements of corona initiation by Ensign D. DePackh, United States Naval Reserve, of the Naval Research Laboratory. (*Lieutenant Commander John H. Neher, chairman, Army–Navy Radio-Frequency Cable Co-ordinating Committee.*)

Aircraft Groups Active at Winter Meeting

Two technical sessions, a meeting of the air transportation committee, a meeting of the subcommittee for aircraft electric rotating machinery, and a conference on aircraft electricity gave aviation a leading place in the winter-meeting program.

The question of the handling of aircraft technical papers in the absence of national technical meetings during the present emergency occupied the attention of the air transportation committee meeting and the conference on aircraft electricity. Encouragement of local discussion groups and, if possible, preliminary presentation of would-be technical papers before local groups was recommended as a method of keeping up the supply of papers dealing with aircraft. The committee on air transportation will continue to formulate a procedure of soliciting, reviewing, and presenting papers.

The status of standards for aircraft electric systems was summarized at the air-transportation meeting by J. R. North, and is reported elsewhere in this issue (*p. 122*). The method of attacking the problem of evaluating types of electric systems for aircraft from the standpoint of alternating or direct current and the selection of voltages and frequencies was discussed.

At the conference on aircraft electricity W. A. Petrasek (A'36) of the American Airlines, Inc., New York, N. Y., emphasized the need for the utmost in reliability and serviceability of systems and equipment and pointed out that military and commercial requirements in this connection were not necessarily identical.

At the meeting of the subcommittee for aircraft electric rotating machinery, which is responsible for drafting test codes and Standards, it was agreed that further work on Standards must wait until the environmental standards to be issued by National Aeronautical Standards Council are available. The immediate efforts of the subcommittee will be devoted to a test code for d-c aircraft machines. Each member will review AIEE Standard 501, recommend additions necessary for adapting it to aircraft machinery, and advise on the material believed to be suitable without change.

Whether or not temperature is a suitable basis for rating an aircraft motor or generator also was discussed at the subcommittee meeting. Statistical methods of demonstrating equipment life are highly desirable, it was said, but should be flexible enough to be satisfactory for military equipment with an expected life of 500 hours and for commercial equipment which must be suitable for much longer life and which must be evaluated in terms of cost, pay load, maintenance, and replacement. W. F. Fell stated that the air lines would demand 2,000 to 3,000 hours' life. Other estimates went higher and lower. In general, however, it was believed that expected life would be short enough to make actual life tests practicable. F. B. Hornby declared that the air lines would be satisfied, if no maintenance were required between engine overhauls—probably 1,000-hour intervals for postwar airplanes. M. L. Schmidt (M'43) of the General Electric Company, Fort Wayne, Ind., mentioned experience with demands for motors to operate for the life of the airplane without attention.

On the whole it was agreed that with the rapid development of new materials, if temperature is to be the basis of rating of equipment, some entirely new values must be set to match environment, materials, and life requirements.

The explanatory introduction accompanying the table of recommended voltages adopted by the air transportation committee at the winter meeting for one year's trial use was reviewed by the subcommittee. No values listed in the table were changed, but provision for one-second tests and clarification of field-test values were added to match American Standard C50. (*D. R. Shoults, chairman, AIEE committee on air transportation.*)

E. L. Bailey (F'43) Chrysler Corporation, Highland Park, Mich., who presented a paper at the session on industrial power applications

Sections Committee Has Lengthy Agenda

The transfer of Mexico from District 3 to District 7 as a step toward establishing another District was the subject for a unanimously adopted motion at the meeting of the Sections committee held in New York on January 24. Another transfer approved by the committee was that of Allen County, Ohio, from the Toledo to the Dayton Section.

After a discussion of the effect of the cancellation of national technical meetings upon the clinic method of treatment of Section operation and management problems, it was decided that the clinics should be continued on a District or area basis. Satisfaction with the clinic plan was found among delegates to the St. Louis meetings, who were polled by means of a questionnaire. A demand for less formal meetings at which more time would be devoted to discussion among the delegates also exists, and this has been considered in planning future clinics. It also is planned to conduct clinics falling under the travel ban by mail.

The growth and interest in technical groups and subsections is reflected in the committee's report that the supply of folders on both types of organization has been exhausted. Four subsections have been organized within the year bringing the total to 13. As an example of the effect of subsections on AIEE membership in general, M. S. Coover (F'42) vice-president for District 5 cited the Arrowhead Subsection formed where originally only two AIEE members resided. Attendances of 90, 80, and 78, respectively, were recorded for the first three meetings. Twelve applications for membership were received almost immediately, and more are on the way.

Additions to the technical groups during the year number 15, and others are reported under consideration.

A plea for more newsworthy items about Section activities and for submission of Section papers which might be suitable for publication in *Electrical Engineering* was made by H. H. Race (F'39) chairman of the publication committee.

R. M. Pfalzgraff (M'41) vice-chairman of the Sections committee outlined the more liberal appropriations now allowed to Sections and reviewed the ways in which Sections could take advantage of these increased appropriations.

Problems of Section operation and management, Section publicity, the simplified report of Section chairman, revision of the pamphlet on Section activities, local section write-up on duties of Section officers, the report of the subcommittee on civic responsibilities of engineers, the organization of local engineering councils, increasing the number of Section operating committees, distributing member activity information, and the status of the third man permitted an allowance to attend one District meeting a year, also were discussed at the meeting. G. W. Bower (M'40) chairman of the Sections committee presided. (*A. C. Muir, secretary, AIEE Sections committee.*)

Committees and Subcommittees Meet During Winter-Meeting Week

Following their usual practice, many of the AIEE committees and subcommittees held meetings in New York, N. Y., during the 1945 winter technical meeting. Actions of interest to the membership taken at some of these meetings are outlined in the following paragraphs which have been prepared from reports submitted by the committee chairmen. Other committee meetings are reported separately.

MEMBERSHIP

The membership committee, which met Thursday afternoon, January 25, reports that current membership applications are being received at a favorable rate equal to the same period for 1943–44. The number of transfers to higher grades of membership is almost equal to that obtained for the corresponding period for last year. The only unfavorable aspect of the membership picture is the decline in the number of Student members from whose ranks new members of Associate grade can be recruited. It is expected that the downward trend in the number of Student members, which is now 1,300 below last year, will continue for a time, since it is a direct reflection of the impact of the war on the colleges.

The committee also expressed appreciation for the response of AIEE members to its request for the names of persons thought to be qualified for membership. L. F. Howard (M'25) chairman of the committee, presided.

LAND TRANSPORTATION

It was announced at the meeting of the land transportation committee Thursday morning, January 25, that the committee had been successful in producing several papers in its field which are now available. The subjects covered are: measurement of railway-motor temperatures, dynamic braking on traction motors; new developments in end-to-end, train-to-train, and train-to-wayside communication; the carbon-shoe insert for current collection from overhead contact systems; and the engineering problems involved in the maintenance of motor armatures. Other papers in preparation, according to the committee, deal with ventilating processes on electrically driven vehicles, air-conditioning for city transit, railway electrification as a potential market for power, Diesel-electric locomotive costs. The suggestion by Llewellyn Evans (F'41), chief consulting electrical engineer for the Tennessee Valley Authority, Washington, D. C., that the power from such projects might be used for low-cost electric-traction projects in the vicinity of the power source is being given further consideration by Mr. Evans at the request of the committee. H. C. Griffith (M'35) chairman of the committee, presided.

INSTRUMENT TRANSFORMER SUBCOMMITTEE

At the meeting of the instrument transformer subcommittee of the instruments and measurements committee on Thursday, January 25, a proposed revision of the American Standard C57 was reviewed for the AIEE and substantially approved with a few minor changes. The proposed revision was prepared by a joint working committee of the relay subcommittee of the committee on protective devices and the instrument transformer committee of the American Standards Association. Paul MacGahan (F'42) chairman of the subcommittee, presided.

SUBCOMMITTEE ON STATIONARY CONTACTS

A survey sheet prepared by the subcommittee on conduction in stationary contact surfaces is now ready for distribution, it was revealed at the meeting of the subcommittee on Thursday, January 25. The subcommittee wishes to obtain data on causes of failure from users of contacts. The subcommittee expects the survey to aid in determining the basic principles required for future standardization of electrical contacts.

It was decided to revise and expand its paper, "Temperature Limits and Abstracts of Present Standards and Practicesfor Stationary Contact Surfaces," presented at the 1945 winter technical meeting. W. P. Dobson (F'43) chairman of the subcommittee, presided.

INSULATION RESISTANCE SUBCOMMITTEE

Investigating the physical and dielectric qualities of various silicone resins is the newest assignment of the subcommittee on insulation resistance which met Thursday, January 25, A. M. de Bellis (M'33) chairman of the subcommittee, revealed. The ultimate object of the investigation will be preparation

MEMBERSHIP ACTIVITY

The Membership Committee wishes to thank the members of the Institute for the splendid response to the request for names of persons thought to be qualified for membership in the Institute. Again we say the interest of the individual member in this regard is important and helpful.

Lawrence F. Howard

Chairman, Membership Committee

L. L. Ray (A '44) General Electric Company, Fort Wayne, Ind., illustrates a paper at the session on aircraft electric apparatus and utilization

of recommendations for committee adoption which will set definite operating limits for these new insulating materials. Though it generally was agreed that immediate standards for silicones would be premature, it also was pointed out that considerable time would be required to collect information, and it was agreed that a working group should be appointed.

The fourth draft of "Recommended Practice for Insulation Resistance Testing of Rotating Machinery" was reviewed at the meeting and was approved with slight changes. It is expected that the recommended practices will be available for action by the electric machinery committee and for distribution within the next few months.

MERCURY-ARC RECTIFIER SUBCOMMITTEE

Meeting twice on January 22 and again on January 24 during the winter technical meeting, the mercury-arc rectifier subcommittee accepted three of the five sections which will comprise the Standards on mercury-arc rectifiers to be presented by the subcommittee to the American Standards Association within the next few months. In addition the subcommittee voted to sponsor a report on "Inductive Co-ordination of Rectifier Equipment," and a working group was appointed to prepare such a report. C. H. Willis (F '42) chairman of the subcommittee, presided.

SUBCOMMITTEE ON FAULT-CURRENT-LIMITING DEVICES

Some points of disagreement arising from the revision which AIEE Standard 32 is undergoing were smoothed out at a meeting of the subcommittee on fault-current-limiting devices held January 22. With only a few items remaining for its attention, the subcommittee expects that the revised Standard will be ready for balloting about July 1.

A questionnaire on "Present-Day Grounding Practices" is being prepared by the subcommittee as the basis of a report which will modernize and replace the reports of 1923 and 1931 on grounding practices. This project, according to the subcommittee, is still in its early stages. F. R. Longley (M '42) chairman of the subcommittee presided.

RESEARCH

Anticipating renewed research activity among colleges and universities at the close of the war, the research committee at its meeting on January 24 instituted plans to bring its lists of worth-while research projects abreast of the times. Such lists were distributed among educators several years ago as guides for graduate and undergraduate research in the field of electrical engineering. The committee will welcome any suggestions for such projects from Institute members. W. A. Lewis (M '39) chairman of the committee, presided at its meeting.

Drugs in Electric-Shock Treatment Topic at Safety Meeting

The paper, "The Use of Drugs in Resuscitation From Electric Shock," which was read by W. R. Smith (F '30) chairman of the AIEE safety committee, in the absence of the author, Cecil K. Drinker, professor of physiology, Harvard School of Public Health, Cambridge, Mass., keynoted the discussion at the well-attended joint committee meeting and conference held January 23.

It was emphasized that the administering of any injections deemed desirable by an attending physician as a stimulant, sedative, or pain killer, obviously is a matter of medical decision with which the discussion was not concerned. The discussion and paper considered drugs as an important aspect of first aid in electric-shock cases from the standpoint of their value in aiding resuscitation. Experience indicates that many doctors are too prone to resort to injections as a means of inducing natural breathing, it was brought out.

Doctor Drinker's paper considered the possible value of available substances and concluded that there is no known drug that has been shown to be effective in restoring breathing to normal. Furthermore, Doctor Drinker stated that nothing can be as beneficial as adequate lung ventilation by manual artificial respiration, and he assigned paramount importance to reliance on the latter method.

Discussion also dwelt upon the need for more widespread dissemination of information on approved manual techniques of artificial respiration to the members of the medical profession by competent medical authorities. Case histories continue to show that, in spite of the acceptance of appropriate manual techniques and the universal endorsement of the prone-pressure method by the medical profession, especially those members eminent in the field of physiology, there are still too many instances in which the importance and significance of such procedure is not recognized by doctors ministering in some way to electric-shock cases. Of equal importance with an understanding of the life-saving possibilities of manual artificial respiration as a first-aid measure is the appreciation of the critical importance of promptness of application in the electric-shock case. This has been stressed in all authoritative writings on the subject, but a more literal acceptance of its truth by all doctors, it is believed, would lead to a more general understanding of the need for saving every possible second of time. The committee will endeavor to promote realization of this fact and will seek the counsel of members of the medical profession in determining how best to do it.

The development of new and novel electric equipment, as electric fences, insect screens, and traps, has demonstrated the need for additional information on the maximum currents that human beings reasonably might be expected to withstand without fatal results, according to Mr. Smith. In this connection C. F. Dalziel (M '39), associate professor of electrical engineering, University of California, Berkeley, summarized the results of the research work on let-go currents carried on under his direction. Professor Dalziel's investigations appeared in AIEE *Transactions* as three papers: "Electric Shock" (written in conjunction with J. B. Lagen and J. L. Thurston) volume 60, pages 1073–8; "Effect of Wave Form on Let-Go Currents," pages 739–44, and "Effects of Frequency on Let-Go Currents," pages 745–50 of volume 62, December section. Discussion by H. B. Williams (M '41) of Columbia University, New York, N. Y., and S. P. Ferris (F '34) of Bell Laboratories disclosed a need for more extensive data than those presented in their paper prepared jointly with B. C. King and P. W. Spence (M '34) of Bell Laboratories ("Effect of Electric Shock on the Heart," *Electrical Engineering*, volume 55, May 1936, pages 498–515). Chairman Smith promised consideration would be given to ways and means by which such research might be undertaken.

From the discussion of the subject of grounding of circuits with voltages in excess of 150 volts to ground, the opinion emerged that there undoubtedly would be some increase in the hazard to personnel, if circuits above this voltage (in the low-voltage class up to 550 volts) were grounded. Present code requirements, under which the grounding of circuits operating at voltages up to 300 volts to ground is merely recommended, and those in the class above 300 volts are left for optional decision depending upon conditions, are considered best.

In his report to the committee Mr. Smith directed attention to the column, "Safety," in the January 1944 issue of *Electrical Engineering* which inaugurated a feature to be continued as a means for the dissemination of information on matters of interest in the fields of electrical safety and allied subjects. He announced that Albrecht Naeter (M '30) Oklahoma Agricultural and Mechanical College, Stillwater, had prepared a communication to be sent to Student Branch counselors and chairmen which would be forwarded in the near future. Revision of the "Bibliography on Electrical Safety" is contemplated and will be carried forward as promptly as conditions permit. It was also announced that the proposed conference on static electricity would be held at an appropriate future time. (*W. R. Smith, chairman, AIEE committee on safety.*)

Variety of Types Discussed at Circuit-Breaker Session

At the technical session on circuit breakers held January 23 and presided over by H. E. Strang (M '39) four technical papers were presented.

The development of 3,500,000-kva three-cycle circuit breakers of the conventional tank-type oil-circuit-breaker configuration and a new compressed-air breaker was outlined in two papers by H. L. Byrd and E. B. Rietz (A '42) (A High-Capacity High-Voltage Three-Cycle Oil Circuit Breaker) and by B. S. Beall, III (A '41) and H. L. Byrd (A Three-Cycle 3,500-Megavolt-Ampere Air-Blast Circuit Breaker for 138,000-Volt Service). Supporting data were presented, com-

C. R. Hanna (M '39) chats with Past Director L. W. Chubb (F '21); both are with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

paring these with previous designs and covering factory tests of both interrupting and reclosing performance.

A companion paper by Philip Sporn (F '30) and H. P. St. Clair (M '29) (Field Tests and Performance of Heavy-Duty High-Speed 138-Kv Circuit Breakers—Oil and Air-Blast) covered in considerable detail the results of extensive field tests on both of these breakers on the system of the Ohio Power Company. Short-circuit duty was available for these tests in wide range of steps up to 3,500,000 kva, which is the full rating of both breakers. This is the first time that short-circuit duty of this magnitude has been available for such field proof testing, which was agreed generally both by the authors and by those discussing the papers to be a highly desirable check on factory test procedure.

The fourth paper, "The Next Step in Interrupting Capacity—5,000,000 Kva," was by A. W. Hill (M '41) and W. M. Leeds (M '38) and presented data to support the selection of 5,000,000 kva as the next interrupting step for high-voltage circuit breakers. It is recognized that factory test facilities cannot be made available for tests at this duty, and a number of equivalent test procedures at lower amounts of power were discussed and their merits and limitations outlined. The results of tests of a new line of high-voltage circuit breakers under several of these methods led to the conclusion that high-voltage circuit breakers rated 5,000,000 kva could be made available, when the industry requires such a rating. (*H. E. Strang, chairman, AIEE committee on protective devices.*)

Annual Index for 1944 Is Available on Request

Contrary to the practice of recent years, the 1944 index to *Electrical Engineering* and AIEE *Transactions* will be issued in limited edition, available upon written request. For the past several years, the annual index has been mailed with *Electrical Engineering* as Section 2 of an early issue of the succeeding year. The decision to publish the index in limited edition and distribute it separately represents a further step in the conservation of our restricted supply of paper.

As announced in the February issue (*page 75*) the 1944 index has been delayed because of the delay in publishing the flood of 1944 technical papers and discussions. With the completion of that material, the index also has been completed and is now ready for distribution.

Copies of the index are being mailed without request to all members of all AIEE technical committees. In addition, copies are being sent to all subscribers to *Electrical Engineering* and to the "Supplement to Electrical Engineering—Transactions Section," because many subscribers retain or bind their copies for reference purposes. Others may obtain a copy without charge by writing to the AIEE order department, 33 West 39th Street, New York 18, N. Y.

STANDARDS • • •

Preliminary Standard for Aircraft D-C Apparatus

In view of the general recognition of the need for preferred voltage ratings for aircraft d-c electric apparatus which will be acceptable to manufacturers and users as a basis for voltage standards for aircraft systems and equipment a "Preliminary Standard for Aircraft D-C Apparatus Voltage Ratings" was recommended for one year's trial use by the air transportation committee on January 24. J. D. Miner, Jr. (M '42) of the Westinghouse Electric and Manufacturing Company, Lima, Ohio, was chairman of the subcommittee preparing the Standard.

The committee believes that many difficulties and much confusion will be elimi-

Preliminary Standard for Aircraft D-C Apparatus Voltage Ratings†

This Standard applies to all types of aircraft d-c electric apparatus.

Nominal system designation	12	24	**120
Generators			
Rated voltages	15	30	125
Voltage adjustment range (per cent)	+0 to −15	+0 to −15	+0 to −15
*Continuous-duty devices			
Rated voltages	13	27	115
Voltage range (per cent)	±10	±10	****±10
*Intermittent-duty devices			
Rated voltages	12.5	26	*** 115
Voltage range (per cent)	±10	±10	****±10
Battery-operated devices			
Rated voltages	11.5	23	
Voltage range (per cent)	±25	±25	
Dielectric tests (R.m.s volts for one minute at 60 cycles, or 120 per cent of value shown for one second)			
Factory test volts	500	500	1,250
Field test *before* use (Clean and dry only —75 per cent)	375	375	950

Apparatus is to function satisfactorily over the voltage ranges given, but with performance not necessarily in accordance with guarantees at rated voltage.

† Recommended for one year's trial use by the AIEE air transportation committee January 24, 1945.

* For operation from a voltage-regulated system. If operation is required from battery alone, use voltage values for battery-operated devices.

** No battery is contemplated for this system, and for this reason, the nominal system designation and the system voltage are identical.

*** It is assumed that most 115-volt wiring will be applied on the basis of thermal rating, and provision for higher-voltage regulation on intermittent loads has not been made.

**** ±10 per cent provides for some error in setting voltage regulators on a system that does not have the stabilizing influence of a battery.

nated by adopting suitable standard voltage ratings for all aircraft electric equipment. These standard voltages then should be made a part of specifications, and name plates should be marked accordingly. Apparatus should be designed for satisfactory operation over the voltage ranges given in the table but without the same performance guarantee as that for rated voltage. Performance data and acceptance tests should be on the basis of standard voltages. The committee recognizes the fact that special applications may require operation over wider voltage ranges than those shown.

Standardization of voltage ratings for aircraft electric accessories is especially difficult because of the close margins for application of aircraft equipment. The great majority of systems in use today are designated as 24-volt systems, since they employ 12-cell lead-plate storage batteries in parallel with the system. This designation has been established thoroughly by a long period of usage and will not be changed, despite the fact that, ordinarily, no part of the system operates at 24 volts. A 24-volt motor, if actually designed and tested for operation at 24 volts, may be considerably overloaded when operated from a system maintained at a voltage high enough to keep a 24-volt battery reasonably well charged.

Although the battery represents only a small portion of the available system capacity its limitations determine the voltages which must be used, and voltage ratings must be set accordingly. System voltage must be high enough to maintain the battery in a charged condition but not high enough to cause excessive battery heating. Twenty-four-volt systems usually are operated at between 27 and 28.5 volts at the point of regulation. Voltage is adjusted by setting the generator regulators, and the particular value chosen is at least partially dependent on the condition of the batteries. Generators must be capable of 30-volt output over the specified speed range to allow for voltage drops totaling $1^1/_2$ volts minimum (including the voltage drop in any paralleling resistors used) between each generator and its regulated point.

To obtain minimum weight, aircraft-system wiring is deliberately loaded heavily, and allowance must be made for voltage drop between the regulated point and the electric accessories. Best weight economy dictates the use of higher cable ratings for intermittent loads than for continuous loads. Rated voltage has been selected as 27 volts for continuous-duty devices and as 26 volts for intermittent-duty devices.

Accessories such as engine-starter motors must be capable of operation when the battery is the sole source of power. They also must operate after one or more generators have been paralleled with the battery, and in most cases they must be suitable for operation from 30-volt starter trucks.

Dielectric-test voltages for used or repaired equipment are not included in the table because sufficient information upon which to base a standard is not available. Dielectric tests should not be made unless the machine is clean and dry, and, even after thorough cleaning and drying, a used machine cannot be expected to withstand more than a fraction of the original factory test voltage. Testing used equipment at 40 to 50 per cent of the test voltage for new machines is rather common practice. Several Army technical orders recommend a 220-volt test for 12-

and 24-volt generators, or 44 per cent of the original test voltage.

These matters have all been studied carefully by a subcommittee of the AIEE air transportation committee, and the tabulation gives recommended standard voltages and voltage ranges for d-c aircraft equipment.

AIEE Aeronautical Standard Work Progresses

Four subcommittees of the air transportation committee with specific assignments and definite membership have started work on their respective standardization problems, since the AIEE announced its program of co-operation with other interested organizations in October 1944 (*EE, Nov '44, p 412*), according to a report presented by J. R. North (F '41) to the air transportation committee meeting held during the AIEE winter technical meeting.

The subcommittees and the scope of each listed by Mr. North, who is liaison representative between AIEE and the Society of Automotive Engineers, the National Aeronautical Standards Committee, the National Electrical Manufacturers Association, the Army Air Forces, and the Navy which are the other interested groups, follow.

AIRCRAFT ELECTRIC SYSTEMS

Preparation of an informative report on "Fundamental Characteristics of Aircraft Electric Systems," has been undertaken by this subcommittee of which R. H. Kaufmann (M '41) of the General Electric Company, Schenectady, N. Y., is chairman.

The report will present the basic considerations involved in securing the most effective aircraft electric application technique. It will cover:

(*a*). An explanation of fundamental electrical problems.

(*b*). Characteristic data for finding the abilities and limitations of devices and apparatus which comprise aircraft electric systems.

(*c*). Systematic procedures for analysis or computation of aircraft-electric system performance.

(*d*). General application practices.

The range of this work is indicated by the subject topics in the report, which will include:

1. General considerations.
2. Power and utilization equipment.
3. Control and protective equipment.
4. System considerations.
5. Definitions.
6. Working standards.
7. Electric-system design procedures.
8. Methods of computing and evaluating.

Various authorities throughout the industry, including users, designers, and manufacturers, will be requested to contribute material based on their particular knowledge and experience. The report is not intended to be in any way mandatory or restrictive, and all contributions will be appreciated.

AIRCRAFT ELECTRIC CONTROL AND PROTECTIVE DEVICES SUBCOMMITTEE

This subcommittee under the chairmanship of R. A. Millermaster (M '34) of Cutler-Hammer, Inc., Milwaukee, Wis., will prepare electrical Standards and test codes covering aircraft control and protective devices to aid in their rating, testing, and application or evaluation for aircraft service.

One of the most important problems being studied by this group is circuit-breaker characteristics, particularly their performance in adequately protecting cables.

AIRCRAFT WIRE AND CABLE SUBCOMMITTEE

Preparation of electrical Standards and test codes covering the rating, testing, and application of aircraft wires and cables is being carried on by this subcommittee of which W. S. Hay is chairman.

AIRCRAFT ELECTRIC ROTATING MACHINERY SUBCOMMITTEE

The setting up of electrical Standards, test codes, and definitions for aircraft electric rotating machinery has been assigned to the subcommittee. Immediate attention is being given to the formulation of a suitable test code for aircraft d-c machines, and a report on proposed standard voltages for aircraft d-c equipment has been issued (*see p. 121*). J. D. Miner, Jr. (M '42) of the Westinghouse Electric and Manufacturing Company, Lima, Ohio, is chairman of the subcommittee Group.

SECTION • • • • •

Quiet Trolley Described Before Michigan Section

A description of the evolution and performance of a "noiseless" streetcar was the feature of a talk on modern developments in city transit equipment which was presented before a recent meeting of the AIEE Michigan Section by S. B. Cooper, transportation application engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The streetcar discussed, known as the "PCC" street car because it was designed by the Presidents Conference Committee set up by the larger transit companies to study metropolitan traffic services, insures quieter operation through the use of rubber truck springs and rubber-packed wheels, the absence of movable parts that rattle, and three kinds of brakes that operate without jolt or causing sway. Additional advantages over the old streetcars include speed comparable with that of an automobile, a built-in ventilating system, glare-free lighting, and soft, roomy seats.

Because of the general interest of the subject, members of the Detroit City Council and of highway and city planning commissions, as well as the public, were invited to attend the meeting.

Iowa Section Meets With Collins Radio Association

Members of the AIEE Iowa Section were entertained by the Collins Radio Company's technical association at a dinner meeting in Cedar Rapids, Iowa, February 6.

A discussion and comparison of present train control systems with a new radio train control system were given by E. A. Dahl, electronics engineer, and A. E. Ganzert, electrical engineer, of the Rock Island Railroad. Included in the talks was a description of the experiments conducted by the railroad on radio systems, both frequency modulation and amplitude modulation, from 28 to 2,600 megacycles. The talks were elucidated with slides. Afternoon trips to the Collins Company's main plant and to the generating station of the Iowa Electric Light and Power Company preceded the dinner.

PERSONAL • • • •

Soren Hanson Mortensen (A '09, M '12, F '20) chief electrical engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., has been awarded the AIEE Lamme Medal for 1944, "for his pioneer work in the development of self-starting synchronous motors and for his contributions to the development of large hydraulic and steam-turbine-driven generators." Mr. Mortensen, who was born in Eskelund, Denmark, November 4, 1879, was graduated from the Polytechnicum of Mittweida, Germany, in 1902 with the degrees of electrical and mechanical engineer. Previously, from 1896 to 1898, he had gained experience as apprentice in various Danish firms and attended technical schools in Thisted and Aarhus and had served as a second lieutenant in the Danish Army. Leaving Denmark for the United States, he was employed from 1903 to 1905 as draftsman and mechanical engineer by the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. In 1905 he joined the Bullock works (then the Bullock Electric Company) of the Allis-Chalmers Company, Cincinnati, Ohio, as draftsman and designer of d-c motors and turbogenerators and in 1908 was transferred to Milwaukee. In the latter year also he was naturalized in the United States. After shifting his work to a-c turbogenerators in 1909, he was made designing electrical engineer in charge of synchronous motors and generators in 1911. He was named engineer in charge of the company's a-c design in 1932 and chief electrical engineer in 1942. Mr. Mortensen holds a number of patents for specific design features of large salient-pole machines and large air- and hydrogen-cooled turbogenerators. In 1944 he received the honorary degree of doctor of engineering from the Illinois Institute of Technology. He has been a frequent contributor to electrical periodicals and is the author of a textbook, "Electrical Machine

S. H. Mortensen

W. E. Wickenden

F. F. Evenson

F. L. Lawton

H. B. Wolf

Design," and of the section on "A-C Generators and Motors" of the McGraw-Hill "Standard Handbook for Electrical Engineers." An active AIEE member, Mr. Mortensen currently is serving as a director of the Institute and has served on many AIEE committees, including those on electrical machinery, application to iron and steel products, Standards, publication, and the Edison Medal. He has served as secretary and chairman of the Milwaukee Section. Since 1937 he has been Allis-Chalmers representative on the electric-equipment committee of the Edison Electric Institute. He is a member of National Electrical Manufacturers Association committees and represents that body on several committees of the American Standards Association.

W. E. Wickenden Nominated for AIEE President

William Elgin Wickenden (A '07, M '13, F '39) president, Case School of Applied Science, Cleveland, Ohio, has been nominated to serve as president of the AIEE for the 1945–46 term. Doctor Wickenden, who was born on December 24, 1882, in Toledo, Ohio, was graduated from Denison University with a bachelor-of-science degree in 1904. In addition, he has been awarded honorary degrees of doctor of engineering by Lafayette College in 1926, Worcester Polytechnic Institute in 1927, the Case School of Applied Science in 1929, and the Rose Polytechnic Institute in 1932. He also received the degrees of doctor of science from Denison University in 1928 and Bucknell University in 1930, that of doctor of laws from Oberlin College in 1930, and that of doctor of humane letters from Otterbein College in 1933. Doctor Wickenden's professional career began in 1904 with an appointment as an instructor in applied electricity at Mechanics Institute, Rochester, N. Y. In 1905 he joined the faculty of the University of Wisconsin, Madison, as assistant in physics, becoming instructor in electrical engineering the following year. He was named assistant professor of electrical engineering in 1909 and in 1914 associate professor at the Massachusetts Institute of Technology, Cambridge. In 1918 he joined the Western Electric Company, New York, N. Y., as personnel manager and in 1921 he became assistant vice-president, American Telephone and Telegraph Company, New York. From 1923 until 1929, when Doctor Wickenden became president of the Case School, he was director of investigation of engineering education, sponsored jointly by the Society for the Promotion of Engineering Education and the Carnegie Corporation. In addition to his AIEE vice-presidency in 1943–44, his AIEE activities include service on the committees on education, 1918–19 and 1922–23, technical program for 1922–24 and 1937–38, Student Branches for 1928–29, Edison Medal for 1942–43, and Cleveland Section chairmanship in 1936. Doctor Wickenden has served as chairman of the Ohio Highway Planning Board, as vice-chairman of the American Council on Education, and as vice-president of the American Association for the Advancement of Science. He is a fellow of the AAAS and a member of the SPEE, the American Society of Mechanical Engineers, the American Academy of Political and Social Science, and the Cleveland Engineering Society. He was awarded the AIEE Lamme Medal in 1935.

Evenson, Lawton, Wolf, Fields, and Robertson Are Nominated for Vice-Presidents

Franklin Fenelon Evenson (A '21, M '29) consulting engineer, San Diego, Calif., and vice-president and general manager, American Products Inc., San Diego, has been nominated as AIEE vice-president for the Pacific District (8). Born in Iron River, Wis., on May 14, 1897, Mr. Evenson received a bachelor-of-arts degree in mechanical engineering from Stanford University in 1920 and an electrical-engineering degree in 1921. From 1921 until 1924 he was associated with the City of Los Angeles (Calif.) Bureau of Power and Light as junior electrical engineer. He was with the Benson Lumber Company, San Diego, Calif., in 1924 in lumber sales and manufacture and in 1928 he entered the special construction department of the San Diego Gas and Electric Company. In 1929 Mr. Evenson engaged in consulting engineering. In this capacity he was chief electrical engineer in charge of the electrical department of the California Pacific International Exposition, 1934–35, and, in 1940, he designed and supervised construction of the transmission and distribution system of the Mountain Empire Electric Cooperative, Inc., Campo, Calif. Mr. Evenson assisted in the preliminary organization of the AIEE San Diego Section (1938), served as chairman of the Section (1938–40) and served as a member of the national nominating committee in 1943. He is a member of the Electric Club of San Diego and the Engineers Club of San Diego, and has served as vice-chairman of the engineering committee of the Chamber of Commerce.

Frederick Lewis Lawton (A '25, M '36) assistant chief engineer, Aluminum Company of Canada, Ltd., Montreal, Quebec, has been nominated for AIEE vice-president for the Canada District (10). Born in London, England, December 14, 1900, Mr. Lawton was graduated from the University of Toronto in 1923 with the degree of bachelor of applied science in electrical engineering. After graduation, he joined the General Electric Company, Schenectady, N. Y., first on test and later in the general engineering laboratory and the engineering general department on transmission-system stability investigations. During 1926–27 he was with the Quebec Development Company, Ltd., at Isle Maligne, as assistant to the electrical engineer engaged in the construction of power-transmission facilities in the Saguenay district. In 1927 he joined the Duke-Price Power Company, Ltd., later the Saguenay Power Company, Ltd., as assistant to the superintendent of operation. He became electrical engineer in 1930 and chief engineer in 1937. He was appointed assistant chief engineer of the Aluminum Company of Canada, Ltd., in 1941. Mr. Lawton is chairman of the AIEE Montreal Section. He is a member of the Engineering Institute of Canada, the Canadian Electrical Association, and the Corporation of Professional Engineers of Quebec. He is also the author of a number of papers on diversified engineering subjects.

Herman B. Wolf (A '26, M '37, F '45), superintendent of maintenance, Duke Power Company, Charlotte, N. C., has been nominated as AIEE vice-president for the Southern District (4). Born in Dallas, N. C., September 10, 1896, and graduated from the Baltimore Polytechnic Institute in 1915, he was employed in 1916 by the Southern Power Company, which later became the Duke Power Company. He served in system maintenance and construction as repairman, foreman, and maintenance engineer, and, in 1941, was appointed superintendent of maintenance. Mr. Wolf de-

veloped testing methods and equipment for use in maintenance of generating, transmission, and distribution apparatus. He also developed high-voltage protective equipment, mobile emergency equipment, and equipment for fire protection. He has contributed a number of technical papers to the Institute and served as chairman of the North Carolina Section in 1941. He has also served as a director of the North Carolina Society of Engineers, president of the Charlotte Engineers Club, and trustee of Lenoir-Rhyne College.

W. C. Smith

W. I. Slichter

L. M. Robertson

Ernest S. Fields (A '20, M '26, F '29) vice-president, the Cincinnati (Ohio) Gas and Electric Company, has been nominated for AIEE vice-president for the Middle Eastern District (2). Mr. Fields was born in Bracken County, Ky., on August 27, 1897. He entered the employ of the Union Gas and Electric Company, Cincinnati, in 1918, as maintenance electrician and operator; in 1920 became chief electrician; and in 1922 was appointed assistant engineer. In 1929, after two years with the Columbia Engineering and Management Corporation, Cincinnati, he returned to the Union Gas and Electric Company as manager. Mr. Fields joined the staff of the Cincinnati Gas and Electric Company as manager in 1936 and was made vice-president in 1943. He was a charter member of the Cincinnati Section when it was organized in 1920, secretary of the Section in 1924 and 1925, and chairman in 1931. He has served on the AIEE national nominating and membership committees. Mr. Fields is, at present, chairman of the general engineering division of the Edison Electric Institute.

Lawrence Marshall Robertson (A '27, M '38) in charge of the transmission and station engineering department, Public Service Company of Colorado, Denver, has been nominated for AIEE vice-president for the North Central District (6). He was born in Denver on January 20, 1900, and was graduated from the University of Colorado in 1922 with a degree of bachelor of science in electrical engineering. He also holds degrees of electrical engineer and master of science from the University of Colorado and a bachelor-of-laws degree from the Westminster Law School. He has been with the Public Service Company of Colorado since 1922 and has been in charge of the transmission and station engineering department since 1925. From 1935 to 1940 Mr. Robertson was chairman of the engineering division, Rocky Mountain Electrical League. He was vice-chairman of the AIEE Denver Section for 1940–41, chairman for 1941–42, and, at present, is serving on the AIEE committees on power transmission and distribution and electrical machinery. Mr. Robertson is a member of the Colorado Society of Engineers and the Colorado Engineering Council.

Smith, North, Flanigen, Nominated for Directorships

Walter Charles Smith (A '07, M '26, F '40) Pacific district engineer, the General Electric Company, San Francisco, Calif., has been nominated to serve on the AIEE board of directors. Mr. Smith, who was born in Clarkston, Mich., on January 9, 1882, was graduated from the University of Michigan in 1905. In the same year, he entered the testing department of the General Electric Company at Schenectady, N. Y. All subsequent experience has been with that company. In 1907 he was made assistant designer of reactors and railway compensators, and in 1908 he was transferred to Pittsfield, Mass., as chief designer. During his period in Pittsfield he rose to the position of assistant engineer of the transformer engineering department. From 1918 until 1920 he did special investigation work for this department with his headquarters at Denver, Colo., and in 1920 he was made transformer specialist at the San Francisco office. He became assistant engineer in 1931 and chief engineer in 1932. He was appointed engineer of the Pacific district in 1940. Mr. Smith was chairman of the AIEE Pittsfield Section for 1912–13 and of the San Francisco Section for 1933–34. He was chairman of the program committee at the AIEE Pacific convention in San Francisco in 1939 and vice-president of the Pacific District (8) in 1941–42. He is past chairman of the San Francisco Engineering Council and past director of the San Francisco Engineers Club. In 1925 Mr. Smith received the Coffin Award from the General Electric Company for transformer design.

John Rainsford North (A '21, M '29, F '41) assistant chief electrical engineer, Commonwealth and Southern Corporation, Jackson Mich., has been nominated to serve on the AIEE board of directors. Mr. North was born in Cambridge, Mass., on February 20, 1900, and in 1923 received a bachelor-of-science degree in electrical engineering from the California Institute of Technology, Pasadena. During his last year at the California Institute of Technology he was assistant instructor in the electrical-engineering department and after graduating joined the Westinghouse Electric and Manufacturing Company at East Pittsburgh and Sharon, Pa., as student engineer. He became associated with the Commonwealth and Southern Corporation in 1927 as an engineer in the investigations division. In 1927 he was made assistant investigations engineer, in 1931, general engineer, in 1937, general technical engineer, and in 1939, assistant chief electrical engineer. Mr. North was chairman of the AIEE Michigan Section in 1934–35 and chairman of the AIEE Standards committee for the year 1942–43. He has been a member of the protective devices committee, the electric machinery committee, and the committee on the economic status of the engineer, and has served as AIEE representative on the electrical standards committee of the American Standards Association. He is a member of the Edison Electric Institute.

John Monteith Flanigen (A '22, M '25) distribution engineer, plant accounting Georgia Power Company, Atlanta, has been nominated to serve on the AIEE board of directors. He was born on November 25, 1895, in Athens, Ga., and in 1917 was graduated from the Georgia School of Technology. During the first World War he served as a lieutenant in the United States Army Coast Artillery Corps and upon his discharge in 1919 entered the employ of Henry L. Doherty and Company as a cadet engineer at Toledo, Ohio. After training, he was transferred to Danbury, Conn., as general engineer. In 1920 Mr. Flanigen was with the Cumberland and Westernport Electric Railway, Cumberland, Md., and in 1921 with the Massillon (Ohio) Electric and Gas Company. He entered the employ of the Ohio Public Service Company, Alliance, in 1921 as distribution engineer. In this capacity he designed and put through the rebuilding of practically the entire distribution system of Alliance. In 1927 he joined the Georgia Power Company as assistant superintendent of retail operation, becoming distribution engineer in 1939. Mr. Flanigen was a member of the AIEE committee on protective devices for 1937–38.

W. I. Slichter Renominated for AIEE Treasurer

Walter Irvine Slichter (A '00, M '03, F '12) professor emeritus of electrical engineering, Columbia University, New York, N. Y., has been renominated for the office of AIEE treasurer which he has held since 1930. Professor Slichter was born in St. Paul, Minn., on May 7, 1873, and was graduated from Columbia University with the degree of electrical engineer in 1896. He was associated with the General Electric Company, Schenectady, N. Y., from 1897 to 1904. During this time he spent five years

E. S. Fields

J. M. Flanigen

J. R. North

as assistant to C. P. Steinmetz on a-c machinery design. In 1910 he was appointed professor and head of the department of electrical engineering at Columbia University and has been professor emeritus since 1941. His AIEE activities include representation of the Institute on the board of the Engineering Library and on the Engineering Foundation board and service on the AIEE committee on inter-American engineering co-operation and as AIEE representative on the Joint Committee on Inter-American Co-operation, and service in numerous other committees.

L. R. Gaty (A '39, M '43) formerly assistant electrical engineer, Philadelphia Electric Company, has been appointed acting electrical engineer, of the electrical-engineering division. A graduate of Cornell University, Mr. Gaty had been assistant electrical engineer since 1940. **C. C. Farrell** (A '41) engineer in charge of system planning succeeds Mr. Gaty. Mr. Farrell joined the Philadelphia Company in 1921 and has been superintendent of overhead and underground lines and superintendent of estimating and detailing. **H. A. Dambly** (A '24, F '42) assistant engineer in charge of special investigations has been transferred to the position of engineer in charge of system planning. Mr. Dambly, a graduate of Pennsylvania State College, received his master-of-science degree from Massachusetts Institute of Technology in 1923, the year he joined the Philadelphia Electric Company. **A. H. Kidder** (A '29, M '39) formerly assistant engineer of system planning, transmission, and distribution, replaces Mr. Dambly as assistant engineer in charge of special investigations. Mr. Kidder is a graduate of the Massachusetts Institute of Technology. **F. J. Berger** (A '27) senior engineer, has been named to Mr. Kidder's former position.

W. D. Coolidge (A '10, M '34) vice-president and director of research, General Electric Company, Schenectady, N. Y., has retired. Doctor Coolidge holds the degree of bachelor of science from the Massachusetts Institute of Technology and the degree of doctor of philosophy from the University of Leipzig, Germany. Doctor Coolidge's development of ductile tungsten was an important step in the emergence of the modern incandescent lamp, and he also produced a radically new type of X-ray tube. He is the holder of 83 patents and has a partial interest in many others. He joined the General Electric Company in 1905, became assistant director of its research laboratory in 1908, associate director in 1928, and director in 1932. Among the many honors bestowed upon Doctor Coolidge are the Edison Medal, the Faraday Medal, the Franklin Institute medal, the Hughes Medal, the Rumford Medal, the John Scott award, and the Washington award. He is a member of numerous scientific societies in the United States and Europe and has received the honorary doctor-of-science degree from Union College and Lehigh University.

D. G. Shepherd (M '22) formerly general manager, Electric Specialty Company, Stamford, Conn., has been elected president of the company. A 1902 graduate of Pratt Institute, Mr. Shepherd first was employed as foreman for the Mann Electric Company, New York, N. Y., until 1904. From 1904 to 1906 he was manager of an electrical contracting and repair business in Sandusky, Ohio. After a six-month period with the Western Electric Company, Chicago, Ill., he became experimental and commercial testing engineer and foreman for the Emerson Electric Manufacturing Company, St Louis, Mo. In 1911 he was appointed engineer and general manager of the Electric Specialty Company. **W. H. Haines** (A '17, M '25) sales manager of the company, has been elected vice-president and general sales manager. Mr. Haines received his engineering degree from Columbia University in 1912 and was associated with the Crocker-Wheeler Company, Ampere, N. J., and the Bethlehem Shipbuilding Corporation before he joined the Electric Specialty Company in 1921 as designing and sales engineer. In 1924 he became sales manager.

A. W. K. Billings (A '07, F '13) formerly vice-president of the Brazilian Traction, Light, and Power Company, Ltd., Rio de Janiero, has been elected president of the company. Mr. Billings was graduated from Harvard University in 1895 and received the degree of master of arts in 1896. He joined the Havana Electric Railway Company in 1899 as assistant general manager, later becoming chief engineer of that company and the Havana Central Railroad Company. From 1909 to 1911 he was engineering manager of J. G. White and Company, Inc., New York, N. Y., and thereafter went to Barcelona, Spain, as managing director of the Ebro Irrigation and Power Company, Ltd. During World War I he served as a lieutenant commander in the United States Naval Reserve. Afterwards he became a consulting engineer first in Barcelona and then for the Canadian Engineering Agency, New York. In 1924 he was appointed vice-president of the Brazilian Power Company.

W. L. Everitt (A '25, F '36) director of operational research, Office of Chief Signal Officer, United States War Department, Washington, D. C., has been appointed professor and head of the department of electrical engineering, of the University of Illinois, Urbana. Professor Everitt holds the degrees of electrical engineer from Cornell University, master of science from the University of Michigan, and doctor of philosophy from Ohio State University. He commenced his teaching career in 1924 as instructor at the University of Michigan, Ann Arbor, and in 1926 joined the faculty of Ohio State University, Columbus, as assistant professor. He was named associate professor in 1929 and full professor in 1934. Concurrently with his professorial duties he worked on communication engineering for the American Telephone and Telegraph Company and for the Signal Corps; he is the author of "Communication Engineering."

H. B. Reynolds (M '41) formerly superintendent of motive power of Interborough Rapid Transit division of the New York City Transit System, has been made superintendent of power generation for the entire transit system. Mr. Reynolds first joined the Interborough Rapid Transit Company in 1914 as assistant engineer. After a period of employment elsewhere he returned to the company in 1919 as mechanical engineer. With the consolidation of the city's subway systems in 1940 he became superintendent of motive power for the IRT division. He is the author of several technical papers and articles and a member of the American Society of Mechanical Engineers.

C. R. Hanna (A '24, F '44) manager of the electromechanical department of the Westinghouse Research Laboratories, East Pittsburgh, Pa., has been appointed an associate director of the Laboratories. Mr. Hanna was graduated from Purdue University in 1922 and has been associated with the Westinghouse Company in the development of new apparatus since that time. In 1936 he designed a gyroscopic regulator for steel-mill-roll motors, a basis for the tank-gun stabilizer developed in 1940. For the invention of this device, which enables Allied tanks to fire accurately while in motion, Mr. Hanna received a Presidential Citation in 1942.

A. K. Stricker, Jr. (A '43) principal industrial specialist on the staff of Major General Roger B. Colton in the office of the Chief Signal Officer, Washington, D. C., recently received the exceptional civilian service award, highest civilian commendation of the War Department. Mr. Stricker's citation reads: "In recognition of his outstanding planning and organizational ability in the development of systems which greatly facili-

tated the procurement, storage, packaging, and issue of Signal Corps equipment. By his perseverance and untiring efforts he contributed immeasurably to the Nation's war effort."

J. B. Harris, Jr. (A '17) formerly vice-president, Rumsey Electric Company, Philadelphia, Pa., has been elected president of the company. He was graduated from the Bliss Electrical School in 1911 and at various times was associated with the General Electric Company, the Westinghouse Electric and Manufacturing Company, and the Pittsburgh Transformer Company. In 1920 he became a member of the firm of Harris and Evans (later Harris and Butler), subsequently becoming its president. In 1935 he was made manager of the electrical-equipment department of the Rumsey Company and in 1939 became vice-president.

J. J. Taylor (A '37) formerly assistant chief engineer, Barberton division of the Ohio Brass Company, has been appointed chief engineer. Mr. Taylor was graduated from the University of Alberta, Canada, in 1928 and immediately entered the test course of the Canadian General Electric Company, Peterborough, Ontario, Canada, later becoming a designer in the induction-motor design department. In 1930 he was employed by the Canadian Ohio Brass Company, Niagara Falls, Ontario, and in 1931 joined the Ohio Brass Company in Barberton as test engineer, becoming development engineer in 1931. Since 1943 he had been assistant chief engineer.

C. W. Leihy (A '30, M '38) manager of publications, Electrical Publications, Inc., Chicago, Ill., and formerly colonel in the United States Army, Washington, D. C., has been awarded the Legion of Merit for "services as a member of the Current Section, Operations Division, and later as Chief of Coordination and Reports Section, War Department General Staff, from February 1942 to September 1944." In his latter capacity, Colonel Leihy prepared the official War Department reports of operations which are rendered daily to the President and to the Chief of Staff.

J. H. Hunt (A '07, M '13) formerly director of the new-devices section of the General Motors Corporation, Detroit, Mich., has been elected engineering vice-president–secretary of the Motor Wheel Corporation. A 1905 graduate of the University of Michigan and a former professor at Ohio University, Mr. Hunt had been with the General Motors Corporation since 1920 and had directed its new-devices section since 1932. He holds a number of patents and is the author of several technical articles.

J. M. Trotter (A '33, M '42) formerly electrical engineer with the Fisher body division of the General Motors Corporation, Chicago, Ill., has been appointed vice-president and chief engineer of the Royal Electrical Manufacturing Company, Chicago. A 1932 graduate of the University of Notre Dame, Mr. Trotter was associated with the Commonwealth and Southern Corporation, Jackson, Mich., from 1937 until he joined the General Motors Corporation in 1943.

T. O. Rudd (A '26) sales engineering department, Kerite Insulated Wire and Cable Company, New York, N. Y., has been elected a vice-president of that concern. He received a bachelor-of-science degree from the Sheffield Scientific School, Yale University, in 1924 and then entered the cadet engineering course of the Philadelphia (Pa.) Electric Company. Mr. Rudd joined the staff of the Kerite Company in 1926.

David Sarnoff (M '23) formerly colonel in the United States Signal Corps, has been promoted to the rank of brigadier general. General Sarnoff, who joined the Signal Corps Reserve in 1924, is on leave as president of the Radio Corporation of America. He recently was awarded the Legion of Merit for his services in the reopening of communications in Paris.

R. D. Cutler (A '20) vice-president, the Hartford (Conn.) Electric Light Company, has been elected a director of that company. Mr. Cutler was graduated from Yale University in 1907 and has spent his entire business career with the Hartford Company. He was made a vice-president in 1936.

W. A. Brecht (M '39) manager of transportation engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been announced as one of seven recipients of the Order of Merit, highest recognition for achievement awarded by the company.

S. B. Hart (A '44) assistant professor of electrical engineering, department of electrical engineering, Swarthmore College, Swarthmore, Pa., has been appointed application and development engineer, industrial electronics, Radio Corporation of America, Indianapolis, Ind.

D. S. MacCorkle (A '30) sales engineer, Habirshaw Division, Phelps Dodge Copper Products Corporation, New York, N. Y., has resigned. Mr. MacCorkle had been with the company for eight years.

A. K. Bushman (M '26) formerly district manager, industrial department, General Electric Company, Chicago, Ill., has been made manager of application and service engineering, in the apparatus department at Schenectady, N. Y.

James Larkin (A '44) district sales manager, Century Electric Company, New York, N. Y., was recently elected president of the Brown Engineering Association of Brown University, Providence, R. I.

OBITUARY . . . .

Philander Betts (A '96, M '99, F '13) Belmar, N. J., retired chief engineer of the New Jersey Board of Public Utilities Commissioners and colonel in the United States Army Reserve Corps, died February 6, 1945. Colonel Betts was born on May 28, 1868, in Nyack, N. Y. After his graduation from Rutgers College in 1891, he entered the employ of the Field Engineering Company, New York, N. Y., in the capacity of foreman on electric railway construction. He joined the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., in 1893, and in 1895 went to Washington, D. C., as an engineer with the Bureau of Yards and Docks of the Navy Department. Colonel Betts was appointed an instructor in the electrical-engineering department of George Washington University, Washington, in 1901, later becoming head of the department. He became chief engineer of the New Jersey Board of Public Utilities Commissioners in 1910 and remained in that position until his retirement in 1934. During the first World War he rose to the rank of lieutenant-colonel in the Quartermaster Corps of the United States Army. Colonel Betts' AIEE committee memberships include the board of examiners, 1914–16 and 1921–23; economics of electric service, 1914–19 (chairman 1915–17); meetings and papers, 1915–17; and safety codes, 1924–30. He was a member of the American Society of Mechanical Engineers, the Illuminating Engineering Society, American Electric Railway Association, and the New Jersey Society of Professional Engineers and Land Surveyors.

Harold Leigh Huber (M '23) foreign wire relations engineer, operation and engineering department, the American Telephone and Telegraph Company, New York, N. Y., died February 4, 1945. Mr. Huber, who was born on May 5, 1889, in Rockyford, Colo., attended Cornell University. He became a plant engineering inspector for the Chesapeake and Potomac Telephone Company, Baltimore, Md., in 1913 and in 1914 district plant engineer. In 1919, after serving as first lieutenant with the United States Army Signal Corps during the first World War, he returned to the Chesapeake and Potomac Telephone Company as division plant engineer in West Virginia. Mr. Huber was promoted to engineering assistant in 1920, appraisal engineer in 1925, and in 1927 transferred to the American Telephone and Telegraph Company as foreign-wire-relations engineer. He was a member of the United States National Committee of the International Electrotechnical mission and the Standards council of the American Standards Association and was one of the AIEE representatives on the Electrical Standard Committee.

John Franklin Meyer (A '08, M '13) retired, former physicist, Bureau of Standards, Washington, D. C., died October 30, 1944. Born in Penn Hall, Pa., on March 11, 1875, he received a bachelor-of-arts degree from Franklin and Marshall College in 1894, a master-of-arts degree in 1897, and, in 1904 a doctor-of-philosophy degree from the University of Pennsylvania. He was assistant professor of physics at the University of Pennsylvania, Philadelphia, in 1906, and professor of physics at Pennsylvania State College, State College, in 1907. In 1909 he entered the employ of the Westinghouse Lamp Company, Bloomfield, N. J., where he was in charge of research. Doctor Meyer joined the Bureau of Standards in 1913 to do research on public-utility standards of service. He served on various AIEE committees including the lighting and illumination committee and the Standards com-

mittee, and was a member of the Illuminating Engineering Society, the American Physical Society, and the Washington Academy of Science.

John Wright Willison (M '26) operation superintendent, Yorkshire Electric Power Company, Leeds, Yorkshire, England, died December 16, 1944. Mr. Willison was born in 1885 in Cleveland, Ohio. He attended the Manchester School of Technology and in 1903 entered the telegraph department of the Midland Railway Company, Derby, England. In 1905 he transferred to the locomotive department. Mr. Willison became assistant engineer for the Ashington Coal Company, Northumberland, in 1910. He was assistant plant engineer for Palmers Shipbuilding Company, Yarrow on Tyne, in 1911, and assistant district and maintenance engineer for the Newcastle Electric Supply Company, Newcastle on Tyne, in 1912. During the year 1914 Mr. Willison was an assistant engineer for the Prestea Block A Gold Mining Company of West Africa. He entered the employ of the Yorkshire Electric Power Company in 1915 as district engineer, becoming sectional and control engineer in 1916, and superintendent in 1918.

Frank Conant Gobel (A '05) chief ordnance engineer, United States Navy Yard, Brooklyn, N. Y., died September 16, 1944. He was born in Groton, N. Y., January 27, 1882, and was graduated from Cornell University with the degree of mechanical engineer in 1903. After spending the years, 1903 to 1906, on installation work for the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., he commenced his career at the United States Navy Yard. He served as electrical draftsman until 1909 when he was named ordnance draftsman and engineer. He became chief ordnance draftsman in 1920, supervising ordnance draftsman in 1929, senior ordnance engineer in 1935, and chief ordnance engineer in 1941.

George A. Hughes (A '17) chairman of the board, Edison General Electric Appliance Company, Chicago, Ill., died September 9, 1944. Mr. Hughes was born on April 14, 1871. From 1897 until 1908 he managed the Hughes Electric Company at Fargo, Bismarck, and Dickinson, N. D., Eveleth, Minn., and Glendive, Mont. Following a year as a manufacturer's agent for electrical apparatus in Chicago, Ill., he became president of the Hughes Electric Heating Company, Chicago. When the Edison General Electric Appliance Company was formed in 1918 he became president of that company, and in 1940 Mr. Hughes was elected chairman of the board.

Joseph L. Vergilio (A '41) sales engineer, Cleveland, Ohio, died October 17, 1944. Mr. Vergilio was born in Italy on April 4, 1893. His early business experience, 1914 to 1918, was as a mechanical engineer and draftsman, the Erie (Pa.) Forge Company. He served in the United States Army until 1920 and after being discharged, he became a sales engineer in Cleveland representing various companies including: the Hickok Electrical Instrument Company, the Esterline-Angus Company, the I-T-E Circuit Breaker Company, and the Cochrane Corporation. Mr. Vergilio was a member of the Cleveland Engineering Society.

Alexander Massey Wilson (A '09, M '18) professor of electrical engineering, University of Cincinnati, Ohio, died August 23, 1944. Professor Wilson was born in Stranraer, Scotland, on August 31, 1876, and received his bachelor-of-science degree from Purdue University in 1901. He joined the staff of the University of Kentucky, Lexington, in 1904 as an assistant professor of electrical engineering and became professor of electrical engineering in 1906. Professor Wilson became associated with the University of Cincinnati in 1911. He was a member of the Illuminating Engineers Society.

Karl Chandler Randall (A '02, M '12) assistant manager, switchboard engineering department, East Pittsburgh, Pa., died December 4, 1944. Mr. Randall was born in Colorado Springs, Colo., in 1874, and was graduated from the University of Nebraska. After one year as assistant in the electrical-engineering department of the University at Lincoln, and one year in Central America, he joined the Westinghouse Electric and Manufacturing Company, Pittsburgh, as transformer engineer in 1904. He became switchboard division engineer in 1911 and manager of the switchboard-engineering department in 1920. In 1936 he was named assistant manager.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on February 15, 1945, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Bradt, A. W., general manager and secretary, Hamilton Hydroelectric System, Hamilton, Ont., Canada.

1 to grade of Fellow

To Grade of Member

Adams, A. W., chief of the control section, Bonneville Power Administration, Vancouver, Wash.
Black, C. H., asst. to mgr., engg., General Elec. Co., Philadelphia, Pa.
Caskey, A. D., elec. engr., Public Service Co. of Northern Illinois, Chicago, Ill.
Castellan, G. E., military mechanist (electrical) No. 2 Engineer Base Workshops, R. E., Middle East Forces.
Davis, R. S., division distribution supt., Florida Power & Light Co., Sarasota, Fla.
Dodge, C. C., elec. engr., Stone & Webster Engg. Corp., Boston, Mass.
Doran, J. V., asst. elec. engr., Toronto Transportation Commission, Toronto, Ont., Canada.
Gilcrease, E. E., field engr., Moloney Electric Co., St. Louis, Mo.
Haberl, H. W., relay protection engr., Quebec Hydro-electric Commission, Montreal, Que., Canada.
Harker, D. C., switchgear engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Johnson, J. E., engr., Philadelphia Electric Co., Philadelphia, Pa.
Jones, J. D., division engr., Kellex Corp., Knoxville, Tenn.
Jones, R. W., circuit-design engr., Automatic Electric Co., Chicago, Ill.
Keppy, J. C., district plant engr., Bell Telephone Co. of Canada, London, Ont., Canada.
Morrill, A. R., elec. engr., National Advisory Committee for Aeronautics, Cleveland, Ohio.
Reed, G. M., managing engr., Panel & Equipment Div., General Electric Co., Philadelphia, Pa.
Smith, B. H., electrical design engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Summerfield, D. N., staff member, Mass. Inst. of Technology, Cambridge, Mass.
Wheeler, J. W., Product Engr., Sperry Gyroscope Co., Great Neck, N. Y.
White, E. L., asst. to chief engr., Bonneville Power Administration, Portland, Oreg.
Whitney, E. C., electrical design engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

21 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1945, or May 31, 1945, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Bennett, W. H., Inst. of Textile Tech., Charlottesville, Va.

1 to grade of fellow.

To Grade of Member

Barrett, A. C., S.I.D.G., Admiralty, Cardiff, Wales.
Beals, V. H., North Little Rock Elec. Co., No. Little Rock, Ark.
Bolenbaugh, R. K., A. P. Foster Co., Reading, Ohio.
Cady, M. C., U. S. Engineers, Sacramento, Calif.
Corbitt, H. E., Waugh Laboratory, Pasadena, Calif.
Crawford, R. C., General Elec. Co., Philadelphia, Pa.
Delong, A. J., Boeing Aircraft Co., Seattle, Wash.
Diehl, C. J., Automatic Elec. Co., Chicago, Ill.
Dodds, F. C., Mountain States Tel. & Tel. Co., Phoenix, Ariz.
Franklin, A. C., Johnson & Phillips, Ltd., London, England.
Gerlovin, S., United Shipyards, Ltd., Montreal, Que., Can.
Gooding, F. H., Okonite-Callender Cable Co., Paterson, N. J.
Hodgson, R. W., Cons. Engr., Sherman Oaks, Calif.
Hubbard, B. R. (Reelection), Whitney Blake Co., New Haven, Conn.
Johnston, O. E. (Reelection), Bonneville Power Adm., Vancouver, Wash.
Korenblat, A. I., I. K. Elec. Co., Little Rock, Ark.
Korenblat, M. T., I. K. Elec. Co., Little Rock, Ark.
Kratz, J. A., Linde Air Products Co., New York, N. Y.
Laycock, W. E., Standard Tel. & Cables, Ltd., London, England.
Levinton, H. L. (Reelection), Bonneville Pr. Admn., Portland, Oreg.
Lewis, R. W., Boston Edison Co., Boston, Mass.
Lo Buono, A. E., Westinghouse Elec. & Mfg. Co., Huntington, W. Va.
Mangum, G. G., U. S. War Dept., New Orleans, La.
McGinnis, O., Western Union Tel. Co., New York, N. Y.
Montgomery, G. H., E. I. Du Pont & Co., Hanford, Wash.
Muench, G. B., Jeffersonville Boat & Mach. Co., Jeffersonville, Ind.
Randall, C. O., U. S. Rubber Co., New York, N. Y.
Rivard, E. P., U.S.C.G. Academy, New London, Conn.
Rowe, N. O. (Reelection), Hercules Powder Co., Wilmington, Del.
Shields, P. E., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.
Watt, R. F., Boeing Aircraft Co., Seattle, Wash.
Wismer, E. W., G. M. Richards & Associates, San Francisco, Calif.
Yeager, L. R., Owens-Corning Fiberglas Corp., New York, N. Y.

33 to grade of Member

To Grade of Associate

United States and Canada

1. NORTH EASTERN

Anson, S. M. (Reelection), Westinghouse Elec. & Mfg. Co., Worcester, Mass.
Bordewieck, R. W., Worcester Poly. Inst., Worcester, Mass.
Buxton, P. W., Pub. Serv. Co. of N. H., Nashua, N. H.
Checavage, A. J., Eastman Kodak Co., Rochester, N. Y.
Clark, F. H., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Dannenberg, W. B., E. B. Badger & Sons Co., Boston, Mass.
de la Torre, J. M., General Elec. Co., Schenectady, N. Y.
Eaton, L. F., Montaup Elec. Co., Fall River, Mass.
Fini, A., Buffalo Niag. Elec. Corp., Buffalo, N. Y.
Fisher, R. M., Jr., General Elec. Co., Schenectady, N. Y.
Goldberg, I. I., General Elec. Co., Pittsfield, Mass.
Humphrey, J. G., Union College, Schenectady, N. Y.
King, E. M., General Elec. Co., Schenectady, N. Y.
Lee, A. J., General Elec. Co., Schenectady, N. Y.
Liebe, H. J., States Co., Hartford, Conn.
Lord, P. E., U. S. Rubber Co., Naugatuck, Conn.
Lund, J. B., Raytheon Mfg. Co., Waltham, Mass.
Macfarlane, G. M., Submarine Signal Co., Boston, Mass.
Maginnis, W. T., Rensselaer Poly. Inst., Troy, N. Y.
May, J. C., Yale Univ., New Haven, Conn.
McMahr, E. L., Boston Edison Co., Boston, Mass.
McNamara, J. E., General Elec. Co., Schenectady, N. Y.
Mergendahl, R., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Miller, F. R., United Illum. Co., New Haven, Conn.
Newton, E. C., General Elec. Co., New Haven, Conn.
Nicholson, C. T., Buffalo Niag. Elec. Corp., Buffalo, N. Y.
Parish, H. D., Int. Business Mach. Corp., Buffalo, N. Y.
Parker, S. R., 2nd Lt., U. S. Army, Cambridge, Mass.
Pihl, G. E., Northeastern Univ., Boston, Mass.
Plotkin, L. E., Stromberg-Carlson Co., Rochester, N. Y.

Sanders, E. H., General Elec. Co. Schenectady, N. Y.
Schneider, D. S., General Elec. Co., Schenectady, N. Y.
Shelton, W. R., General Elec. Co., Pittsfield, Mass.
Snyder, F. D., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Stutz, C. A., Stromberg-Carlson Co., Rochester, N. Y.
Woods, H. E., National Aniline & Chem. Co., Buffalo, N. Y.
Zimmerman, C. B., General Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Alexander, W. M., Lear, Inc., Piqua, Ohio.
Bigleson, A., U. S. Navy Yard, Washington, D. C.
Born, W. F., U. S. Navy Dept., Washington, D. C.
Brauburger, R. A., Lafayette College, Easton, Pa.
Burleson, A. J., Jr., U. S. Navy, Washington, D. C.
Burnside, B. H., Bureau of Ships, U. S. Navy Dept., Washington, D. C.
Christian, C. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Clarke, W. J., Ohio Box Board Co., Rittman, Ohio.
Coffman, F. R., Lear, Inc., Piqua, Ohio.
Converse, L. B., Cincinnati Ord. Dist., Cincinnati, Ohio.
Curtis, C. H., E. I. du Pont de Nemours & Co., Wilmington, Del.
Desch, J. R., Natl. Cash Reg. Co., Dayton, Ohio.
Dinsmer, J. P., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Dugar, W. F., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Frank-Jones, G., Lt., R.N.V.R., Washington, D. C.
George, N. R., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Gray, W., Int. Diesel Elec. Co., Inc., Long Island City, N. Y.
Grebenkemper, C. J., U. S. Naval Res. Labs., Washington, D. C.
Hedene, E. H., Radio Corp. of America, Camden, N. J.
Hesse, J. P., Jr., U. S. Army, Aberdeen Proving Ground, Md.
Hill, J. L., Lear, Inc., Piqua, Ohio.
Holian, A. J., Univ. of Dayton, Dayton, Ohio.
Huddleston, R. H., Jr., Lieut., U. S. Army, Philadelphia, Pa.
Kichline, W. G., Fed. Tel. & Radio Corp., Dayton, Ohio.
Klinger, T. M., Ohio Pub. Serv. Co., Elyria, Ohio.
Konick, A. E., Radio Corp. of America, Camden, N. J.
Leonhart, E. C., Carbide & Carbon Chemicals Corp., South Charleston, W. Va.
Lobban, R. A., Picker X-Ray Corp., Baltimore, Md.
Maybood, H. L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
McCoy, C. W., Equipment Lab., Wright Field, Dayton, Ohio.
Merkle, E. C., Gen. Motors Corp., Vandalia, Ohio.
Michel, M. B., U. S. Navy Dept., Washington, D. C.
Murakami, T., Swarthmore College, Swarthmore, Pa.
Murray, F. E., Phila. Elec. Co., Plymouth Meeting, Pa.
Musser, R. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Nikas, G. J., Philco Radio & Tel. Corp., Philadelphia, Pa.
Parker, J. R., Radio Corp. of America, Camden, N. J.
Postel, H. C., Sperry Gyroscope Co., Inc., Baltimore, Md.
Potter, H. L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Ralph, E. A., Clark Controller Co., Cleveland, Ohio.
Schaffir, H. B., Picker X-Ray Corp., Cleveland, Ohio.
Schneeman, E. E., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Schreiner, E. D., U. S. Naval Res. Lab., Washington, D. C.
Stern, J. L., Radio Corp. of America, Camden, N. J.
Sublette, M. C., Ensign, U.S.N.R., Washington, D. C.
Sweetman, C. E., Philco Radio & Tel. Corp., Philadelphia, Pa.
Tatman, O. B. (Mrs.), Leeds & Northrup Co., Philadelphia, Pa.
Teisman, W. P., Cincinnati Water Works, California, Ohio.
Thomas, R. A., General Elec. Co., Erie, Pa.
Torbit, J. G., General Elec. Co., Philadelphia, Pa.
Towne, R. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
VanDermark, L. H., Lear, Inc., Piqua, Ohio.
Walker, C. B., I-T-E Circuit Breaker Co., Philadelphia, Pa.
Wayant, R. F., General Elec. Co., Dayton, Ohio.
West, H. H., Ensign, U.S.N.R., Washington, D. C.
Wier, D. D., Jr., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Worley, L. M., U. S. Bureau of Ships, Washington, D. C.

3. New York City

Adams, J. B., Jr., Reeves Sound Lab., Inc., New York; N. Y.
Albright, J. D., Western Elec. Co., Kearny, N. J.
Anthony, T. E., U. S. Rubber Co., Passaic, N. J.
Arnold, R. E., Bell Tel. Labs., Inc., New York, N. Y.
Ballou, F. M., M. B. Cutting Co., Jersey City, N. J.
Beachley, V. B., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Bedwell, E. E., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Behrendt, G. M., Fed. Tel. & Radio Co., New York, N. Y.
Bennetts, T. F., Arma Corp., Brooklyn, N. Y.
Berkley, L. S., Burndy Engg. Co., Inc., New York, N. Y.
Boyce, R. P., Fed. Tel. & Radio Corp., East Newark, N. J.
Canz, H. M., Crocker Wheeler Elec. Mfg. Co., Ampere, N. J.
Cavenaugh, D. E., Bell Tel. Lab., New York, N. Y.
Collins, S., U. S. Navy Yard, Brooklyn, N. Y.
Dunn, O. R., U. S. Rubber Co., Passaic, N. J.
Feist, W. E., Cambridge Inst. Co., Inc., Ossining, N. Y.
Goodbar, I., Holophane Co., Inc., New York, N. Y.
Grimmett, R. B., C. I. Lighting Co., Roslyn, N. Y.
Klyce, B. H., Jr., Bell Tel. Labs., Whippany, N. J.
Kups, E. F., Fed. Tel. & Radio Corp., Newark, N. J.
Levander, S. S., Diehl Mfg. Co., Finderne, N. J.
Logue, J. C., Cornell Univ., Ithaca, N. Y.
May, H. F., Teleregister Corp., New York, N. Y.
McCabe, E., U. S. Navy Yard, New York, N. Y.
Miller, D. H., McGraw-Hill Publishing Co., Inc., New York, N. Y.
Palmer, W. E., New York *Times*, New York City, N. Y.
Ruppel, A. E., Bell Tel. Lab., New York, N. Y.
Sarwald, W. D., Weston Elec. Inst. Corp., Newark, N. J.
Schwartz, R. F., Cpl., U. S. Army, Fort Monmouth, N. J.
Shoop, R. M., "Electrical World," New York, N. Y.
Spillane, G., General Elec. Co., New York, N. Y.
Tappan, T. C., Int. Gen. Elec. Co., New York, N. Y.
Young, S. B., Cambridge Inst. Co., Ossining, N. Y.

4. Southern

Anderson, E. H., George G. Sharp, New Orleans, La.
Barkin, I. J. (Reelection), Tenn. Val. Auth., Knoxville, Tenn.
Cornelussen, E., Tenn. Val. Auth., Knoxville, Tenn.
English, J. C., Graybar Elec. Co., Inc., Little Rock, Ark.
Ferguson, D. J., Jr., Tenn. Valley Auth., Knoxville, Tenn.
Fink, F. P., Watson Flagg Engr. Co., Knoxville, Tenn.
Fletcher, V. V., Aluminum Co. of America, Malvern, Ark.
Foster, C. M., U. S. Engineers, Little Rock, Ark.
Frischhertz, R. E., Avondale Marine Ways, Avondale, La.
Goodson, A. B., Naval Operating Base, Norfolk, Va.
Graham, R. L., Lt., U.S.N.R., Greenville, S. C.
Harvill, R. L., Harvill-Byrd Elec. Co., Little Rock, Ark.
Hunter, J. A., Westinghouse Elec. Supply Co., Memphis, Tenn.
Jacobs, P. B., Jr., Tenn. Eastman Corp., Oak Ridge, Tenn.
Johnson, B. E., Higgins Industries, New Orleans, La.
Kimm, E. G., U. S. Engineer Office, Little Rock, Ark.
Landers, A. L., Westinghouse Elec. & Mfg. Co., New Orleans, La.
Lewis, W. A., Jr., Aluminum Co. of America, Malvern, Ark.
Lyons, W. H., Jr., Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Monson, D. J., N.A.C.A., Langley Field, Va.
Newland, L. E., City Electrician, Little Rock, Ark.
Ramler, W. J., Tenn. Eastman Corp., Oak Ridge, Tenn.
Raphael, R., Carbide & Carbon Chemical Corp., Oak Ridge, Tenn.
Ryan, J. C., Westinghouse Elec. & Mfg. Co., New Orleans, La.
Sale, H. C., Higgins Industries, Inc., New Orleans, La.
Strum, P. D., N. C. State College, Raleigh, N. C.
Turregano, P. J., Jr., Southwestern La. Inst., Lafayette, La.

5. Great Lakes

Bank, M. L. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Bellafaire, J. P., Mich. Tool Co., Detroit, Mich.
Bernhard, C. W., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Cooper, S. E., Zenith Radio Corp., Chicago, Ill.
Duncan, V. W., Farnsworth Tel. & Radio Corp., Fort Wayne, Ind.
File, J. L. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Fitzgerald, R. D., General Elec. Co., Fort Wayne, Ind.
George, W. A., Pub. Serv. of Northern Ill., Waukegan, Ill.
Ingram, E. C. G. Conn Ltd., Elkhart, Ind.
Kavlick, C. J., Commonwealth Edison Co., Chicago, Ill.
Larson, W. M., Control Corp., Minneapolis, Minn.
Martindell, C. C., Western Elec. Co., Cicero, Ill.
Mayr, F. J., Allis-Chalmers Mfg. Co., West Allis, Wis.
Polk, H. R., Western United Gas & Elec. Co., Aurora, Ill.
Richardson, B. R., Western United Gas & Elec. Co., Aurora, Ill.
Sandberg, M. C., Control Corp., Minneapolis, Minn.
Sangdahl, A. D., Delta-Star Elec. Co., Chicago, Ill.
Schaupner, A. F., Spaulding Elec. Co., Detroit, Mich.
Schroeder, A. F., Buell & Winter, Engrs., Sioux City, Iowa.
Secly, R. E., General Elec. Co., Fort Wayne, Ind.
Spaulding, J. G., Jr., Spaulding Elec. Co., Detroit, Mich.
Spaulding, R. C., Spaulding Elec. Co., Detroit, Mich.
Toombs, J. E. (Reelection), Ind. Gen. Serv. Co., Marion, Ind.
Van Guilder, W. (Reelection), Precision Scient. Co., Chicago, Ill.
Walker, B. G., Control Corp., Minneapolis, Minn.
Williams, H. C., Commonwealth Edison Co., Chicago, Ill.

6. North Central

Fick, W. A., Mountain States Tel. & Tel. Co., Denver, Colo.
Kemper, V. C., Jr., Gates Rubber Co., Denver, Colo.
Muench, R. R., Amer. Tel. & Tel. Co., Denver, Colo.
Parker, E. H., Amer. Tel. & Tel. Co., Denver, Colo.
Stephens, W. J., Public Serv. Co. of Colo., Denver, Colo.

7. South West

Alberti, A. G., Pub. Serv. Board, San Antonio, Texas.
Arnold, H. D., Emerson Elec. Mfg. Co., St. Louis, Mo.
Ballman, F. C., Baldor Elec. Co., St. Louis, Mo.
Clayton, J. C., Todd-Galveston Drydocks, Inc., Galveston, Texas.
Elliott, E. E., Emerson Elec. Mfg. Co., St. Louis, Mo.
Gettinger, H. J., Emerson Elec. Mfg. Co., St. Louis, Mo.
Jenkins, C. L., R. F. Taylor, Cons. Engr., Houston, Texas.
Lindberg, C. A., Emerson Elec. Mfg. Co., St. Louis, Mo.
Raithel, R. L., Emerson Elec. Mfg. Co., St. Louis, Mo.
Shipp, C. M., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Thompson, W. M., El Paso Elec. Co., El Paso, Texas.

8. Pacific

Axe, F. H., Cons. Vultee Aircraft Corp., San Diego, Calif.
Barry, L. S., General Elec. Co., San Francisco, Calif.
Cooper, R. L., Western Pipe & Steel Co., San Pedro, Calif.
Depew, B. W., General Elec. Co., San Francisco, Calif.
Dobbins, A. H., Calif. Shipbuilding Corp., Wilmington, Calif.
Foote, S. H., Arizona Broadcasting Co., Tucson, Ariz.
Frazee, H. H., N.A.C.A., Moffett Field, Calif.
Gleisberg, A. E., Pacific Gas & Elec. Co., San Mateo, Calif.
Goetz, J. A. (Reelection), Southern Pacific Co., San Francisco, Calif.
Harrington, K. D., Cutler-Hammer, Inc., Los Angeles, Calif.
Karpinos, T. M., Sacramento Air Tech. Serv. Com., Sacramento, Calif.
Lawler, W. L., Engr. Procurement Div., USASOS, San Francisco, Calif.
Maniaci, J. F., G. M. Giannini & Co., Pasadena, Calif.
Martin, G. J., Southern Calif. Tel. Co., Los Angeles, Calif.
Mazzola, E. P., Gardner Elec. Mfg. Co., Emeryville, Calif.
Nourse, M. S., N.A.C.A., Moffett Field, Calif.
Powell, W. W., Coast Elec. Co., San Diego, Calif.
Rich, K. C., Pacific Gas & Elec. Co., San Francisco, Calif.
Schmidt, D. C., Univ. of Calif., San Diego, Calif.
Snow, R. G., 11th Naval Dist., San Diego, Calif.
Tanner, A. R. (Reelection), General Elec. Co., San Francisco, Calif.
Templin, K. W., Byron Jackson Co., Huntington Park, Calif.
Ward, B. D. (Reelection), Army Base, Oakland, Calif.
Watson, C. J., Calif. Shipbuilding Corp., Terminal Island, Calif.

9. North West

Bay, F. H., Pacific Tel. & Tel. Co., Portland, Oreg.
Brazier, E. E., Gen. Elec. Supply Corp., Salt Lake City, Utah.
Cropley, M. L., Puget Sound Pr. & Lt. Co., Seattle, Wash.
David, G. A., Willamette Iron & Steel Corp., Portland, Oreg.
Engels, P. R., Jr., E. I. du Pont de Nemours, Hanford, Wash.
Harrington, O. J., Portland Gen. Elec. Co., Portland, Oreg.
Knorr, A. C., Northwestern Elec. Co., Portland, Oreg.
Mashino, L. L., Montana Pr. Co., Great Falls, Mont.
Paul, B. W., Bonneville Pr. Adm., Vancouver, Wash.
Radcliffe, J. H. (Reelection), Montana Pr. Co., Great Falls, Mont.
Stangell, P. A., Portland Gen. Elec. Co., Portland, Oreg.
Stewart, G. H., City of Spokane, Spokane, Wash.
Whisler, H. L., Portland Gen. Elec. Co., Portland, Oreg.

10. Canada

Bagley, P. E., E. Long, Ltd., Orillia, Ont., Can.
Brian, J. M. (Reelection), RCA Victor Co. Ltd., Montreal, Que., Can.
Carberry, G. E., Ferranti Elec., Ltd., Mt. Dennis, Ont., Canada.
Deane, R., Cemco Elec. Mfg. Co., Vancouver, B. C., Can.
Geary, S. H., Can. Gen. Elec. Co., Ltd., Toronto, Ont., Can.
Doak, F. C., Lower St. Lawrence Power Co., Rimouski, Que., Can.
Hudson, A. C., Research Enterprises Ltd., Leaside, Ont., Can.
Lowry, H. B., Manitoba Tel. System, Winnipeg, Man., Can.
MacCrae, V. C., Lt. Cmdr., R.C.N.V.R., Equimalt, B. C., Can.
Page, J. H., Orillia Water, Lt. & Pr. Comm., Orillia, Ont., Can.
Shanks, V., Sangamo Co., Ltd., Leaside, Ont., Can.
Thompson, R. A., Goodyear Tire & Rubber Co., New Toronto, Ont., Can.
White, L. G., Dominion Magnesium, Ltd., Haley, Ont., Can.
Willey, G. E., N. Slater Co., Hamilton, Ont., Can.

Elsewhere

Chandra, B. K., South Wales Power Co., London, England.
Corlett, E. G., Lt., H. M. Forces, Bombay, India.
Gruenberg, H., Univ. of B. C., Vancouver, B. C., Can.
Iqbal, M., Military Engg. Serv., South East Asia Command, India.
Olea, N., M., Petroleos Mex., Mexico, Mex.
Pardo, I. S., Soc. Electro Mecanica, Mexico, Mex.
Paredes, G., A., Cia Impulsora de Emp. Electricas, Mexico, Mex.
Scheffel, G. E., Electromedidor S.R.L., Buenos Aires, Arg., S. A.
Sinotte, J. L., Cons. Paper Corp., Ltd., Csp de la Madeleine, Que., Can.
Villafana, P., J., Electrica Chapala S. A., Guadalajara, Mex.

Total to grade of Associate
United States and Canada, 246
Elsewhere, 10

OF CURRENT INTEREST

Inventors Council Seeks Solutions to Navy Department Problems

The National Inventors Council recently released a list of inventive problems for which the United States Navy Department is seeking solutions. Included in the list are the following items of possible interest to electrical engineers:

1. A beach-marker light, to be visible from 5,000 yards at sea, with rechargeable or nondeteriorating battery and weighing not more than five pounds.

2. A device for transmitting rotary motion through a moistureproof barrier to be applied to control-knob shafts on radio equipment provided with immersion-proof cases, generator shafts on field telephones equipped with immersion-proof cases, and generator shafts for hand-cranked power supplies for field radio equipment. The device should prevent entrance of water or moisture vapor when immersed to a depth of ten feet, should offer a minimum of frictional opposition to rotary motion, should be small in relation to the equipment to which it is applied, should have ample power-transmission capability, and should be applicable to existing equipment with a minimum of modification.

3. Waterproof jack for microphone, headphone, and key jacks for telephone equipment which would prevent water or moisture vapor from penetrating equipment, even when immersed to a depth of ten feet. The jack should be capable of being cleaned and dried without tools and should accommodate standard plugs.

4. A directional-drum lens for use by the United States Coast Guard in its lighting aids to navigation. The Coast Guard now uses 200-millimeter Fresnel-type drum lenses which provide a 360-degree fan beam of uniform candlepower on the horizon plus an auxiliary spotlight when additional intensity is required. The need is for a single lens which will permit the function of both lights from a single source but whose over-all dimensions will be that of the present lens.

5. A single-unit range light which will indicate with a reasonable degree of sensitivity a vessel's lateral deviation from the center line as it proceeds along a narrow channel. The device must be inexpensive and low in power consumption.

6. A polyphase a-c integral-horsepower motor up to 50 horsepower, whose inrush current does not exceed the running current and whose starting torque equals the running torque.

7. A small portable field-strength meter about the size and weight of a "walkie-talkie" for rapid checking of radio field intensities in the vicinity of radio transmitting stations. The instrument must be simple to use and accurate within plus or minus ten per cent. Frequency range desired is 100 to 20,000 kilocycles, and desired field-intensity range is from 10 to 1,000 millivolts per meter.

8. Radio antennas up to 300 feet in height that can be set up by unskilled ground crews. Very light alloys and special rigs for rapid erection by a ground crew without climbing are desired, in addition to ability to dismantle or collapse into packages not exceeding 20 feet in length. Insulated-base vertical antennas are preferable.

9. Small aircraft-type d-c motors without commutators, slip rings, or any other moving contact arrangements, so as to eliminate service difficulties with commutators and electrical noise produced thereby.

10. A precision twin-triode vacuum tube with the general characteristics of the current 6SN7 type plus additional precision features. It shall be completely nonmicrophonic; the mutual conductance of the two sides, after a 15-minute warm-up, shall be equal over the normal operating range to within plus one per cent; these characteristics are to be maintained over an ambient-temperature range of from +80 to −40 degrees centigrade. It would be possible to produce this tube by mass-production methods with not more than ten per cent rejections.

11. An expendable, compact, lightweight, rugged, mechanical device to permit successive closures of up to eight electric circuits with a time interval between closures of about 0.2 to 0.3 second.

12. A small, fast-acting, double-action solenoid to operate on 28 volts direct current with a stroke of about 0.5 with a 20-pound pull (or push) at condition of maximum air gap. The plunger should "seat" at each end of travel and very probably would have to be an electromagnet whose polarity would reverse at each end of travel.

13. A method of welding high-pressure piping without the aid of backing straps or with back straps which would be soluble in a harmless solution which could be introduced in the pipe before putting same into service.

14. A method of welding light-gage aluminum. This is of particular interest since aluminum lifeboats and life rafts are currently of riveted construction because of the lack of a satisfactory method of welding.

Suggested solutions should be prepared in sketch and description form and submitted to the National Inventors Council, Department of Commerce, Washington 25, D. C.

Seized Enemy Patents Described in Abstracts

Publication of two sets of Abstracts or short descriptions of 45,000 alien-owned United States patents seized by the Alien Property Custodian of the United States Government has been announced by James E. Markham, the Custodian. Licenses to most of the patents, which cover practically every field of manufacture, are available to American citizens at a fee of $15 per patent and are good for the life of the patent.

The Mechanical and Electrical Abstracts (about 37,000 patents) are bound in four volumes comprising approximately 4,000 pages of short descriptions and illustrative drawings and include a 48-page index. The remaining 8,000 patents are classified under Chemical Abstracts. Either set may be obtained for $25 from the Office of Alien Property Custodian, 311 Field Building, Chicago 3, Ill.

If complete sets of abstracts are not desired, sections or classes dealing with any one subject are obtainable at proportional cost. An index showing the section or class titles and prices may be procured free-of-charge from the Alien Property Custodian.

Transmitter–Receiver Designed for Lifeboat Use

A transmitter–receiver for use in lifeboats, equipped for two-way manual radiotelegraph and radiotelephone and for automatic radiotelegraph transmission, which can be operated by nonskilled men, has been announced by the United States Maritime Commission. The radiotelephone will enable occupants of lifeboats so equipped to maintain communications between lifeboats.

The transmitter–receiver will operate on pretuned international distress frequency of 500 kilocycles and on the high frequency adopted by the air/sea rescue program.

The transmitter–receiver is operable entirely by the use of a hand-powered generator. It is entirely waterproof and embodies the use of balloon and kite antennas enabling an average transmitting range ten times that obtainable with the present lifeboat transmitter on 500 kilocycles and a range above 1,000 miles when used on the high-frequency band.

Radio Powered by Two Watts Available in Holland

A new radio set, which uses only two watts of electricity in comparison to the 10- to 20-watt requirements of older models, soon will be obtainable in liberated Holland, according to Aneta, Netherlands news agency. Cost of the radio will be 45 guilders ($24.30).

Because of the acute shortage of electricity, Hollanders who were able to retrieve their radios after the liberation were forced to curtail their usage. For this reason, demand for the new radio, which requires much less power, is expected to be widespread.

OTHER SOCIETIES

Tau Beta Pi—Eta Kappa Nu Hold Joint Meeting

A joint dinner meeting of Tau Beta Pi and Eta Kappa Nu, honorary engineering fraternities, was held January 22, 1945, during the AIEE winter technical meeting in New York, N. Y. Vladimir Karapetoff (F '12) was guest of honor and delivered an address on "Fundamental Concepts of Relativity." He was introduced by Ernst Weber (F '34) professor and head of the graduate electrical-engineering department, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., who outlined the high lights in the speaker's career. Professor Karapetoff became professor emeritus of electrical engineering of Cornell University in 1939, after 35 years at the university and was engaged in activities related to the war when he was afflicted by failing eyesight, culminating in almost total blindness in 1943.

Professor Karapetoff presented his subject in a nonmathematical manner by showing how two observers moving relative to each other would obtain different results in measurements of time and length because of the relative motion. He predicted that the importance of the work of Einstein will become apparent to future generations, in accordance with the pattern of history which shows that the significance of the work of other scientists, such as Newton, was not appreciated widely in their day. In one of several interesting diversions from the main subject, Professor Karapetoff compared a political system to a gyroscope; pressure may be applied with the intention of moving the system in a certain direction, but like the gyroscope the system will move in a new direction at right angles to the pressure, with an irresistible force.

V. L. Dzwonczyk (M '43) assisted in the presentation of illustrative charts. Nearly 200 members and guests were present.

New IRE London Branch Meets; Elects Officers

Election of G. A. Woonton, professor, University of Western Ontario, as chairman was announced recently as a result of the first official meeting of the London, Ontario, Canada, branch of the Institute of Radio Engineers. The meeting took place on November 24, 1944, culminating a year of organizational work.

Other officers elected were: J. R. Bach, manager of the meter department, Sparton Radio, London, as vice-chairman; Robert Wilton, flight lieutenant, Royal Canadian Air Force, Clinton, Ontario, as secretary-treasurer; and as committee chairmen, R. C. Dearle, professor, University of Western Ontario, education; W. J. Blackburn, president, The Free Press, publicity; Burwell Graham, chief engineer, Sparton Radio, London, membership; and K. R. Patrick, wing commander, Royal Canadian Air Forces, Clinton, meeting and papers.

1945 Officers Elected by AIME

Harvey Seeley Mudd was elected president of the American Institute of Mining and Metallurgical Engineers, New York, N. Y., for the year 1945 recently.

Donald H. McLaughlin and Leo F. Reinartz were elected vice-presidents and directors for three-year terms. Others elected directors for three-year terms are: C. H. Benedict, Robert H. Morris, J. C. Nicholls, Clyde E. Weed, Eugene A. White, and W. E. Wrather.

Ice Breakers Add Bow Propeller

A bow propeller supplements the two customary stern propellers in this new-type ice breaker. Driven by a Westinghouse 3,300-shaft-horsepower motor, the propeller can turn in either direction to build up a bow wave for cracking heavy ice or to pull water from under the ice, making it break under its own weight. Each of the stern propellers is driven by a 5,000-horsepower motor, and power for all three is provided by six 1,375-kw Diesel-driven generators. The generators are operated in parallel, and the speed of the propulsion motors is controlled by gradually raising the generator excitation to about 75 per cent of maximum excitation while the engines are run at minimum speed and the motors are excited at minimum value. For higher speeds the engine is raised to maximum speed, and, at the same time the generator excitation is increased from 75 per cent to normal. The motor field is controlled by an automatic current regulator which causes the absorption of the maximum available engine output. Under ice-breaking conditions overloading is prevented by a torque-limiting governor which automatically reduces engine speed

INDUSTRY . . . . .

Committee Is Appointed to Advise on Standards

A committee of eight industrial executives, with C. E. Wilson, president, the General Electric Company, as chairman, has been appointed by the Secretary of Commerce to advise the Department of Commerce and the American Standards Association on future plans for standards work. Also serving on the committee are F. M. Feiker (F '42) dean of engineering, George Washington University, and F. B. Jewett (F '12) president, the National Academy of Sciences.

The appointment is the result of a conference of 50 business leaders held in New York, January 12, 1945, at the invitation of the Secretary of Commerce, to make suggestions to him regarding the relative roles which should be played by the Government and industry in standards activities. At that time it was recommended that industry should provide a strong leadership in the development of national standards, that this should be done in full co-operation with the Government, and that arrangements should be made for broader participation of industry, both organized groups and individual companies, in the work of the American Standards Association. Among other actions taken were formal resolutions that the National Bureau of Standards strengthen its work on the fundamental standards and methods of measurement and on the development of data needed in standardization activities. It also was resolved that in the field of consumer goods, as in other fields, each Standard approved by the ASA must represent the work of those groups which are concerned with its scope and provisions, and no effort must be made to impose Standards on them.

Slide Film Course in Resistance Welding Control. A resistance-welding-control training course, prepared by Westinghouse Electric and Manufacturing Company for its own employees, is being made available to others as a result of requests from engineering groups and individuals interested in the subject. The seven-lesson training course, consisting of 35-millimeter slide sound films, lesson books, quiz book, and an instructor's manual, may be ordered from C. R. Riker, Westinghouse Electric and Manufacturing Company, 306 Fourth Avenue, Pittsburgh, Pa.

Farm Organization Receives Gift. The presentation of a check for $10,000 to the Future Farmers of America, a national organization designed to stimulate the interest and knowledge of farm boys in electricity and its application to the farm, has been announced by the General Electric Company, Schenectady, N. Y. The farm youth organization, which was organized in 1928, has 6,900 active chapters in high schools of the country with an active membership of 240,000 boys.

JOINT ACTIVITIES

ASA Approves New Standard for Sound Level Meters

A new American Standard for sound level meters, superseding a tentative Standard originally issued in 1936, has been approved by the American Standards Association. These meters are used for measuring the intensities of noise and other sounds in order to evaluate their relative effect on the ear.

Work on the new Standard was carried out by a committee of technical experts under the direction of the Acoustical Society of America and brings the tentative standard up to date in accordance with developments in acoustical practice in the sound-measurement field. The standard now includes design objective and tolerance curves for flat response-frequency characteristics of sound level meters and slight revisions in the previous curves for 40- and 70-decibel equal-loudness contours. Data from which the design objective response curves have been plotted are also included.

ECPD to Be Represented On Education Committee

Intended participation in the activities of the Citizen's Federal Committee on Education, recently established to present the layman's point of view on American education, has been announced by the Engineers' Coun-

cil for Professional Development, although a representative has not been chosen as yet.

The Citizen's Committee has been organized to act in an advisory capacity to the Commissioner of Education on policies and on programs of service to education to be carried on by the United States Office of Education. The Committee will meet two or three times each year, and will consist of three persons each from the fields of labor, business, agriculture, manufacturing, and the professions. Also represented will be veterans and service clubs and religious groups.

ECPD Issues Annual Report

The Engineers' Council for Professional Development has announced the issuance of its 12th Annual Report for the year ending September 30, 1944. The report, which is available in booklet form, covers the chairman's report to the Council, reports of the various committees, as well as of the representatives of constituent organizations, and the financial statement for the year. It also includes a list of officers, representatives, and committee personnel; the charter and rules of procedure; and an inventory of publications available through the ECPD.

The ECPD report may be obtained for 25 cents through the secretary of ECPD, 29 West 39th Street, New York 18, N. Y.

EDUCATION . . .

Michigan College Offers Scholarships. Twenty-five additional scholarships for properly prepared and accredited foreign students are now available at the Michigan College of Mining and Technology. These scholarships supplement the previous plan under which one scholarship was offered for each province of Canada and one for each Latin-American nation. Under the new plan students from any foreign country are eligible, and each nation or province is not limited to a single scholarship.

Institute of Industrial Research Organized by University

Organization of the University of Louisville Institute of Industrial Research, a nonprofit corporation which will engage in engineering and scientific research for industrial and private clients on a contract basis, has been announced by the board of trustees of the university.

The institute is the outgrowth of the division of industrial research in the Speed Scientific School, which during the past few years has carried on limited contract research for industry. The new organization, in addition to employment of a small permanent technical staff from different scientific and technical fields, will depend for its assistance in supervision on selected staff members of the engineering and scientific faculty. The research work will be carried on by graduate fellows. The institute will be housed in a new research building, and in addition, will use facilities of the engineering laboratories.

The officers are:

Chairman of the board of managers, E. W. Jacobsen, president of University of Louisville.

President, F. L. Wilkinson, Jr., dean of Speed Scientific School.

Director and Vice-President, R. C. Ernst, professor of chemical engineering.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Calculating Antenna Radiation Patterns

To the Editor:

R. W. Cronshey is to be congratulated on his article, "Calculating Antenna Radiation Patterns," (*EE, Sept '44, pp 331–4*). It gives a semigraphical solution to the problem which is easy to understand and to use, thus making it applicable for classroom use as well as to industrial problems.

However, one error should be noted. At the bottom of the first column on page 332, the author states that the voltage induced (that is, the field strength produced) by two transmitting antennas, N and A, will be directly proportional to the ratio of the radiated powers. This is incorrect, for the field strengths are directly proportional to the ratio of antenna *currents*, or to square root of the power ratio.

Thus in the equation for E_P near the top of column 2 of page 332, the *square root* of each of the power ratios should be taken. Also, a term should be included in the first bracket to account for the field strength due to the radiation from antenna A. The corrected equation then would be

$$E_P = E_A \times \sqrt{\left\{1+\sqrt{\frac{P_B}{P_A}}\cos\left[\theta_B - 360 d_B \cos(\beta_B-\phi)\right]+\sqrt{\frac{P_C}{P_A}}\cos\left[\theta_C - 360 d_C \cos(\beta_C-\phi)\right]+\sqrt{\frac{P_D}{P_A}}\cos\left[\theta_D - 360 d_D \cos(\beta_D-\phi)\right]\right\}^2 + \left\{\sqrt{\frac{P_B}{P_A}}\sin\left[\theta_B - 360 d_B \cos(\beta_B-\phi)\right]+\sqrt{\frac{P_C}{P_A}}\sin\left[\theta_C - 360 d_C \cos(\beta_C-\phi)\right]+\sqrt{\frac{P_D}{P_A}}\sin\left[\theta_D - 360 d_D \cos(\beta_D-\phi)\right]\right\}^2}$$

If these corrections are carried over to Table I of the article, column 4 should have the heading $\sqrt{P_N/P_A}$. The ratio $\sqrt{P_N/P_A}$ for antenna D becomes one-fourth. In Table II the square-root sign should be inserted in the headings, and for antenna D

$$\sqrt{\frac{P_N}{P_A}}\sin = 0.22$$

and

$$\sqrt{\frac{P_N}{P_A}}\cos = 0.12$$

This makes $Y = -1.68$, and $X = 0.57$.

Then $\frac{E_P}{E_A} = \sqrt{(0.57)^2+(1.68)^2} = 1.77$

in the equation below.

H. L. KRAUSS (A '42)

(Assistant professor of electrical engineering, Yale University, New Haven, Conn.)

To the Editor:

Professor Herbert L. Krauss is right when he says that the statement in my article that the induced voltages vary as the ratio of the radiated powers is incorrect. They vary as the *square root* of the ratio of the radiated powers. Consequently, everywhere that the term P_N/P_A is shown, it should be $\sqrt{P_N/P_A}$ instead.

Professor Krauss is also correct in stating that the numeral one (1) has been omitted from the equation for the four-element array. It is wondered if anyone has noticed also that the same numeral one (1) has been omitted from the two radicals which are equated to E_R. For these omissions the author assumes full responsibility. The entire solution was conceived and developed from the graphical standpoint. Only when attempting to offer a rigorous proof were the mathematics introduced. It was here that these terms were erroneously dropped.

It is pointed out that the errors noted above all are errors in algebra and in no way invalidate the principles actually pertaining to the graphical solution itself.

It might be pointed out also that Professor Krauss is in error in his remarks regarding the changing of the values arrived at in the sample problem of Tables I and II. If, as explained here and in the professor's letter, the square-root sign were to be placed around the power ratio in the heading of column 4 of Table I and in the headings of columns 3 and 5 of Table II, the values indicated would in no way need to be altered. Thus, the change of value for antenna D which Professor Krauss quoted will be seen to be the result of one too many square-root signs.

Professor Krauss is to be commended for his close attention to the details of the

mathematical solution. This assistance in perfecting a rigorous proof for the graphical solution is deeply appreciated.

RAYMOND W. CRONSHEY (Student member)
(Second lieutenant, Signal Corps, United States Army, Presque Isle, Me.)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; those and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Electron-Optics. By Paul Hatschek. Translated by Arthur Palmé. American Photographic Publishing Company, Boston, Mass., 1944. 161 pages, illustrated, 9¼ by 6 inches, $3.

This new edition is a translation of a book first published in 1937 in Germany and the translator has added a chapter on the progress made in the field of electronics in the interim. The book imparts the fundamentals of electronics without resorting to mathematics. The descriptions and explanations of electronic phenomena are devised to inculcate a broad general idea of their underlying principles coupled with a historical perspective of the subject as a foundation for understanding electronic applications as they become more widespread.

Testing of Engineering Materials. By C. W. Muhlenbruch. D. Van Nostrand Company, Inc., New York, N. Y., 1944. 200 pages, illustrated, 9½ by 6½ inches, cloth, $2.75. (ESL.)

This book is intended as a text for a one-semester laboratory course for engineering students. Through comprehensive testing of a variety of materials and a careful analysis of the results of the tests, it aims to give the student, a clear picture of those properties that can be illustrated most readily in the testing laboratory and to help him acquire an understanding of the physical properties of the common engineering materials and their possibilities and limitations.

Selected Papers of William Frederick Durand. The Durand reprinting committee, California Institute of Technology, Pasadena, Calif., 1944. Paged in sections, 11 by 8½ inches, fabrikoid, $2.50. (ESL.)

Seventeen selected papers of William F. Durand, from 1896 to 1940, have been reprinted in commemoration of the 85th anniversary of his birth. The subject matter is varied, ranging from aerodynamics to philosophical considerations of science and engineering. A brief biographical sketch precedes the papers, and a bibliography of published works concludes the book.

Mitteilungen aus der Versuchsanstalt für Wasserbau an der Eidg. Technische Hochschule in Zürich, Nr. 4. Theoretische Grundlagen der Fluss- und Wildbachverbauungen. By R. Müller. Verlag AG. Gebr. Leemann and Company, Zurich, Switzerland, 1943. 193 pages, illustrated, 9 by 6 inches, paper, 12 Swiss frs. (7.20 rm.). (ESL.)

This publication summarizes the results of the studies of the movement of detritus which have long had the attention of the hydraulic laboratory of the Zurich technical high school. It presents the available knowledge of theoretical principles and shows how these may be applied practically in the regulation of rivers and torrents.

Radio Amateur's Handbook. 21st edition 1944. Published by the American Radio Relay League, West Hartford, Conn. 480 pages, illustrated, 9½ by 6½ inches, paper, $1. (ESL.)

This standard manual of amateur radio communication, revised annually, consists of two main parts. The principles and design section have been enlarged considerably in the present edition, particularly the chapters on fundamentals and vacuum-tube theory. The construction and data section includes a new chapter on carrier-current communication; and information on some 50 new tubes has been added to the classified vacuum-tube data tables. War emergency radio service is dealt with separately.

Physics. (United States Naval Academy edition.) By E. Hausmann and E. P. Slack. D. Van Nostrand Company, Inc., New York, N. Y., 1944. 857 pages, illustrated, 8½ by 5½ inches, cloth, $5.50. (ESL.)

The essentials of physics are presented clearly and logically. Numerous problems are worked out to illustrate the application of the principles to practical use. A great many problems are provided for solution. This edition has been prepared for the United States Naval Academy, and the text arranged to meet classroom needs there. The revision has been done by the teaching staff of the Academy.

Ultrahigh-Frequency Radio Engineering. By W. L. Emery. Macmillan Company, New York, N. Y., 1944. 295 pages, illustrated, 8¼ by 5½ inches, cloth, $3.25. (ESL.)

Intended for electrical-engineering students with a background in elementary communication and electronics, this text is confined to basic principles. Emphasis has been placed on the discussion of the component parts of ultrahigh-frequency systems. The problems and experiments included provide a comparison between theoretical and experimental results. A list of references accompanies each chapter.

Technique of the Terrain. By H. A. Musham. Reinhold Publishing Corporation, New York, N. Y., 1944. 228 pages, illustrated, 9¼ by 6 inches, linen, $3.85. (ESL.)

This is a text on maps and their uses in field operations in war and peace. It is not concerned with the making and production of maps, nor does it cover the whole subject of topography. The first 12 chapters deal with general considerations such as scales, relief, and co-ordinates; the last four chapters cover briefly aerial photography, tactical topography, maps and logistics, and military geography. Numerous tables of pertinent data are appended for reference use.

Rifles and Machine Guns. By M. M. Johnson. William Morrow and Company, New York, N. Y., 1944. 390 pages, illustrated, 9½ by 6 inches, cloth, $5. (ESL.)

Modern small arms here are analyzed from the practical viewpoint of use. The book describes all the important United States and foreign weapons of the period of World War II from the rifle and pistol to the aircraft machine gun, covering their development, operation, loading, firing, and disassembling and giving data on their ammunition, stoppages, accuracy, and employment. Line drawings and photographs illustrate the text.

Nonferrous Metals. (Postwar Building Studies Number 13.) By a committee convened by The British Non-Ferrous Metals Research Association, His Majesty's Stationery Office, London, England, 1944. 72 pages, tables 9½ by 6½ inches, paper, 1s; obtainable from British Information Services, 30 Rockefeller Plaza, New York, N. Y., 35 cents. (ESL.)

This report provides a practical review of the uses of nonferrous metals in building construction. After the general characteristics of these metals are described, their resistance to corrosion, mechanical properties, and the methods of working and joining them are considered. The report discusses the suitability of each for special uses, such as pipes, tanks, roofing, and fittings. Finally, the recommendations are summarized.

PAMPHLETS • • • •

Postwar Exportation of Capital Goods to Nonindustrialized Areas of the World. By George H. Houston. Machinery and Allied Products Institute, 221 North La Salle Street, Chicago, Ill., 16 pages.

The Steel Castings Industry. Steel Founders Society of America, 920 Midland Building, Cleveland, Ohio, unpaged, no charge.

Production Management. Albert Ramond and Associates, Inc., 6300 Chrysler Building, New York 17, N. Y., 40 pages.

The Future of American Science. By Kirtley F. Mather, Harry Grundfest, and Melber Phillips. United Office and Professional Workers of American, CIO, 1860 Broadway, New York 23, N. Y., 19 pages, $1.50 per hundred, two cents each.

Problems of Mobilization and Reconversion, First Report. By the Director of War Mobilization and Reconversion, Washington, D. C., 58 pages.

The Early Years. The American Petroleum Institute, 50 West 50th Street, New York 20, N. Y., unpaged.

Future Financial Problems of Conversion in the Aircraft Industry. By Tom Lilley and L. Laverne Horton. Harvard Business School, Soldiers Field, Boston 63, Mass., 49 pages, $1.50.

Fundamentals of Industrial Electronics. By G. M. Chute. General Electric Company, Schenectady, N. Y., 40 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Analysis of Arc-Welding Reactors

CHARLES M. WHEELER
NONMEMBER AIEE

Synopsis: It is the purpose of this paper to examine the need and design of arc-welding reactors for d-c arc-welding sets. The inductance useful in stabilizing welding arcs is defined, and methods for calculating and measuring this quantity are suggested. Further, criteria for designs which make most effective use of material are established. Finally, a recent development in reactor design is described.

REACTORS used in d-c arc-welding circuits often have been likened in their action to that of flywheels on engines. Both absorb energy during periods of unwanted energy surplus and release this stored energy to the system during periods when the energy is low. Through this added inertia their respective systems are stabilized; for, whereas the flywheel reduces mechanical pulsations, the welding reactor smooths fluctuations in current. The presence of self-inductance in d-c arc-welding circuits is, therefore, highly desirable—it is, in fact, often essential to the satisfactory operation of single-operator arc-welding generators.

Questions concerning means of procuring this inductance immediately arise. Why are reactors sometimes used, whereas at other times they are not? Fundamentally, what is the nature of welding inductance? How much is required? These questions are important to both designers and users of d-c arc-welding sets, because their answers are reflected in terms of quality of characteristics, and compact efficient equipment.

This paper therefore is concerned not only with the application of welding reactors as a means for improving arc characteristics, but also with methods for arriving at compact efficient designs in which the material is used to best advantage. Finally, a recent development in arc-welding reactors is described.

Are Reactors Required?

A basic consideration confronting the designing engineer is whether the required amount of self-inductance can be incorporated more advantageously in the electromagnetic design of the generator, or whether an external device is more practical. The former alternative may complicate the design and construction of the generator with a resultant increase in weight, whereas the latter, of course, requires that a reactor be used. The alternative which the designer chooses is generally the one resulting in the more effective over-all use of electromagnetic material and the simpler construction.

At one time it was standard practice to use large welding reactors with most generators, but through subsequent refinements in the design of the generators and improvements in welding electrodes the usual reactor accompanying arc-welding generators practically disappeared.

However, the comparatively recent introduction and wide application of 3,600-rpm welding sets have placed a new emphasis on the use of external reactors, because these high-speed generators have inherently less self-inductance than their 1,800-rpm predecessors of similar design. In many cases well-balanced designs require the use of external reactors. The design of reactors for these units merits special attention, for their size and weight must bear a favorable relationship to that of the rest of the equipment.

The Arc-Welding Reactor

The essential elements of a welding reactor (a coil having N turns, a magnetic core with cross section A and length l, and an effective air gap G) are shown in Figure 1. A direct current I, establishes flux ϕ in the core. This reactor supplements a welding generator's characteristics through the addition of self-inductance to the welding circuit.*

Nature of Welding Inductance

It is a characteristic of a d-c arc that the current fluctuates about an average value and may die out suddenly if there is not sufficient stability in the source of power. The function of the reactor is to oppose these fluctuations through a self-induced voltage which is proportional to the rate of change of current. This voltage also supplements that supplied by the generator in establishing a "restriking" voltage when the arc tends to "pop out." The inductance useful in welding, or "welding inductance," should be defined in terms of its effectiveness in stabilizing changes above and below an average current. It should be expressed as the *rate of change* of flux linkages per ampere** as in equation 1.

$$L_w = N\frac{d\phi}{dI}\times 10^{-8} \text{ henrys} \qquad (1)$$

Welding inductance as defined by this equation is a function of current since it is influenced to a large extent by saturation in the magnetic circuit of the reactor. It is a quantity, however, which may be readily calculated in the manner to be described.

Calculation of Welding Inductance

Welding inductance may be calculated directly from the saturation curve for a given reactor as indicated in Figure 2. For any assumed value of current the inductance is proportional to the slope of the saturation curve as indicated. Figure 3 shows the welding-inductance characteristic calculated from the saturation curve in Figure 2.

In this method of calculation, as well as in the analysis of reactor-design con-

Paper 45-29, recommended by the AIEE committee on electric welding for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted November 30, 1944; made available for printing December 11, 1944.

CHARLES M. WHEELER is with General Electric Company, West Lynn, Mass.

* There is a second type of separate electromagnetic device, sometimes called a "d-c transformer," whose elements are the same as those of a reactor, except that a second winding, connected in series with the generator's shunt field, is added. Its function is to apply, through mutual coupling, a forcing voltage on the shunt field of the generator which is proportional to the rate of change of welding current. As a result, the inductance it adds to the welding circuit is relavely low, for the apparent inductance of its series coil is proportional to its leakage flux. The "d-c transformer," therefore, serves principally to improve the dynamic characteristics of the generator with which it is used, rather than add to the stored energy in the welding circuit. Designs often are modified for the purpose of increasing the leakage flux in order to increase the effective series inductance.

The transforming reactor, so called because it performs the functions of a "d-c transformer" and a reactor, is designed with a separate magnetic path for the leakage flux. See reference 1. Whether a d-c transformer or transforming reactor is used depends largely on the inherent dynamic characteristics of the generator and its inherent self-inductance.

** Inductance of coils having iron cores may be variously defined, depending on the basic concept of this quantity. It has also been evaluated in terms of total stored energy and total flux linkages per ampere. See reference 2.

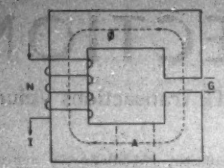


Figure 1. Essential elements of an arc-welding reactor

siderations which follows, the effects of hysteresis and eddy currents on welding inductance are assumed to be insignificant. It has been found from experience that in many applications these factors truly can be neglected, because conventional welding-reactor designs have laminated cores, their air gaps are relatively large, and frequencies associated with the rate of change of flux are fairly low. However, the effects of "stray" flux on welding inductance may be appreciable and should be calculated. Here, "stray" flux is defined as that flux which is established by the coil but does not pass across the air gap of the magnetic circuit. Its paths may lie in the window which accommodates the coil or through parallel magnetic paths near the coil.

Measurement of Welding Inductance

A straightforward method for measuring welding inductance, and one which gives good qualitative values, lies in recording the voltage induced in the reactor winding by current surges from the generator itself. This is easily accomplished in practice by means of a search coil* wound between reactor turns. The search-coil winding should assume, insofar as possible, the same space occupied by the reactor winding in order to include the effects of stray flux on inductance. If the number of search-coil turns is the same as the number of reactor turns, the welding inductance may be calculated directly from an oscillogram by dividing instantaneous values of search-coil voltage, E_s, by the rate of change of current.**

$$L_w = \frac{E_s}{dI/dt} \text{ henrys} \qquad (2)$$

Figure 4 shows data plotted from a representative oscillogram taken on a sample reactor (Figure 2) when the welding generator was suddenly short-circuited. The inductance characteristic determined directly from the oscillogram is shown in Figure 3 for comparison with the characteristic calculated from the saturation curve. It will be noted that the test and calculated welding-inductance characteristics agree very well up to the point where the reactor core saturates. Thereafter the test inductance is appreciably higher. The reason for this apparent discrepancy is that this particular reactor had a parallel magnetic path for stray flux, the effects of which are not included in the saturation curve.

Determination of Welding-Inductance Requirements

The necessary amount of welding inductance in a reactor to be designed for a given generator is best determined from actual welding tests. These tests are conducted at all practical welding currents within the range of the generator using various types of electrodes. Welding-inductance requirements may be determined by inserting a laboratory reactor in the circuit and adjusting its inductance to whatever amount may be required for satisfactory welding characteristics at each value of welding current. The inductance characteristic of the laboratory reactor should, of course, be substantially uneffected by saturation for the range of currents used.

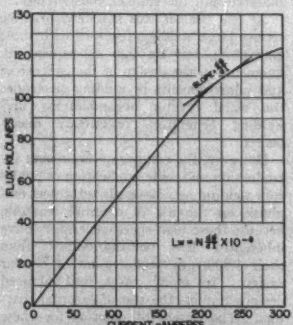


Figure 2. Saturation curve of a representative reactor showing method of calculating welding inductance

These tests provide welding-inductance values required as indicated by points 1, 2, 3, and so on, in Figure 5. In this particular example, it is noted that point 5 defines the required inductance L_w', at a limiting welding current I_w'. These are the values of inductance and average welding current about which a reactor should be designed for satisfactory overall welding performance. There is, however, a steady current I', somewhat higher than I_w', which should be used in design formulas, because the required welding inductance must be effective during current surges above the average as well as at average values. The ratio I'/I_w' can best be determined from experience and analysis of oscillograms taken during actual welding.

Thus the welding reactor for this example should be designed to have 1.1 millihenrys inductance (L_w') at a limiting steady current of 190 amperes (I') as indicated in Figure 5.

The following analysis is a review of design requirements for compact efficient arc-welding reactors, based on the specification that a known value of welding inductance is required at a limiting steady current.

Design of Welding Reactors

The design of coils and of magnetic circuits for series reactors is contingent in a large measure upon each other, for the mechanical configuration of one affects that of the other. The coil design, for example is dependent upon the cross-sectional area of the core and the number of ampere turns specified by the magnetic circuit. Other factors, such as degree of ventilation, heat-dissipating ability of the type of winding used, type of insulation, and duty cycle for which the coil is intended, fix its design when the current, turns, and dimensions of the core are known.

In general, welding inductance may be expressed by the equation,

$$L_w = \frac{3.19N^2A}{G} xf(I, G/l) \times 10^{-8} \text{ henrys} \qquad (3)$$

in which $f(I, G/l)$ is an expression for the shape of the inductance characteristic.

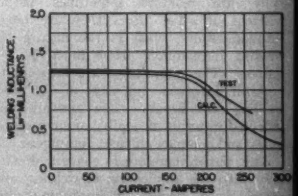


Figure 3. Welding-inductance characteristic
Curve "calc." is from saturation curve, Figure 2.
Curve "test" is from oscillogram, Figure 4

It varies from almost 1.0 for small values of current to practically zero for very large currents. It is immediately apparent that there is an infinite number of combinations of N, A, and G (and l) which will give a desired value of welding inductance at a required limiting current. But relatively few designs will accomplish this end without some extravagance

* The oscillograph element may be connected directly across the reactor winding and the induced voltage determined by subtracting instantaneous values of IR drop.

** A second method for determining welding inductance experimentally lies in superimposing a small alternating current on various values of direct magnetizing current. The a-c inductance so measured is "the welding inductance." The oscillograph method is generally to be preferred, however, for the latter usually presents circuit problems.

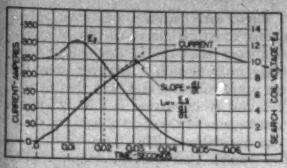


Figure 4. Plot of current and search-coil voltage from oscillogram of open-circuit to short-circuit test, showing method for determining welding inductance

in the use of electromagnetic material. Such a waste would be without advantage to either the designer or the user.

The general problem of design, therefore, is to find not so much *some combination* of materials which will give the desired characteristics as certain *specific combinations* in which the materials are used most effectively for obtaining those characteristics. For the former method of approach is little more than a process of trial and error, whereas the latter is synthesis of design leading to compact efficient apparatus in which unused and unuseful material is eliminated. Through synthesis the product is "tailored" to the requirements of the user.

Now, in welding reactors the performance requirements are that the useful amount of inductance, L_w' shall be obtainable at a limiting current, I'. For most effective use of materials these values should be obtained at a point on the reactor characteristic where the maximum energy useful for welding is available. Just as welding inductance requires specific definition, the energy associated with this inductance must be defined in terms of its stabilizing influence on fluctuations above and below an average welding current. This means that the energy useful in welding is actually incremental energy—the rate of change of energy per ampere. An expression for incremental energy dW/dI, may be determined in the following manner.

Energy stored in magnetic circuits is defined as

$$W = \int EI\, dt \text{ joules}$$

Since

$$E = L_w \frac{dI}{dt} \text{ (from equation 2)}$$

then

$$\frac{dW}{dI} = L_w I \text{ joules per ampere} \qquad (4)$$

For most effective use of materials the maximum incremental energy should occur at the limiting values of inductance and current, or

$$\left.\frac{dW}{dI}\right|_{max.} = L_w' I' \text{ joules per ampere} \qquad (5)$$

The significance of this concept is shown graphically in Figure 6, in which P is a typical welding-inductance characteristic and p is the incremental-energy characteristic as determined from equation 4. Curves Q and R are the inductance characteristics for the same reactor showing, respectively, the effects of increasing and decreasing the air gap 15 per cent. From these curves it is apparent that a change of air gap in either direction results in the loss of welding inductance at I' with a consequent sacrifice in welding characteristics at this current. This loss results from the occurrence of the maximum incremental energy at some current other than I' (see curves of q and r), even though the value of maximum incremental energy is substantially unaffected by changes in air gap.

It is apparent from this analysis that there are specific relationships between turns, core dimensions, and air gap for the most effective use of material. A

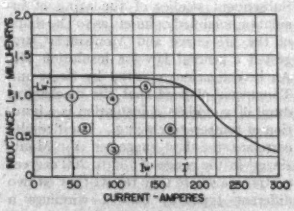


Figure 5. Method for determining welding-inductance requirements from welding tests

L_w' is limiting welding inductance, I_w' limiting average welding current, and I' limiting steady current

departure from these relationships results in a sacrifice in performance or an ineffective use of materials. There are, of course, many possible variations in synthesized designs to meet a specified performance characteristic. Each has a different number of turns and different core dimensions. For example, one has the fewest number of turns and another the lowest weight, but the material in each is used most effectively when the maximum welding energy available is obtained at the limiting performance requirements. From this range of possibilities the designer chooses one which is best adapted to the welding generator.

A New Arc-Welding Reactor

A new arc-welding reactor embodying the principles of most effective use of materials has a unique feature which improves the transient characteristics of the welding generator. This reactor, consisting solely of a U-shaped core and a winding, is mounted on the generator in such a manner that the magnet frame completes its magnetic circuit. In Figures 7 and 8 it is shown in combination with a Bergman split-pole welding generator.

Figure 7 shows the general distribution of flux in the machine at open circuit. It is noted that the magnet frame flux for this condition is confined principally to the top and bottom quadrants. But when current is caused to flow from the generator, the flux in these sections is transferred to the right and left quadrants. This exchange of flux progresses until, at short circuit, the generator flux in the magnet frame is confined principally to the right and left quadrants as shown in Figure 8. During sudden changes in current, it is normally necessary for the generator to supply energy for accomplishing this redistribution of flux.

The flux established by the reactor, on the other hand, increases from zero at no load to a maximum at short circuit. It thus serves to maintain substantially constant flux in the section of frame spanned by the reactor core, eliminating the energy normally required to change the flux in this section. The transient response of the generator is thereby improved proportionately.

A second benefit from this arrangement is the saving in space and weight made possible through the elimination of a large section of the reactor core.

Thus, while its prime function is to supply welding inductance, this reactor is integrated with the welding generator in such a manner that its transient characteristics are improved, and smaller lighter-weight designs are made possible.

Conclusion

The desirability of self-inductance in d-c arc-welding circuits has been established through long experience. Although improvements in generator design have made it practical to include the required inductance in the electromagnetic material of the generator, the recent trend toward smaller lighter-weight 3,600-rpm

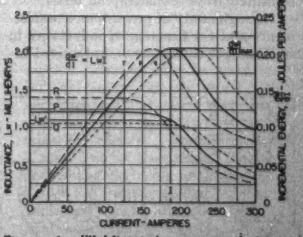


Figure 6. Welding-inductance and incremental-energy characteristics (curves P and p), showing effects of increasing the effective air gap 15 per cent (curves Q and q), and effects of decreasing the effective air gap 15 per cent (curves R and r)

Organo-Silicon Compounds for Insulating Electric Machines

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Synopsis: The general problem of electrical insulation is reviewed in relation to silicone insulating materials. Silicone compounds are described and their chemical and physical characteristics discussed. Thermal stability and moisture resistance of silicone insulation are compared to that of conventional class-*A* and class-*B* insulation. Predictions are made as to the field of usefulness of silicones in electrical insulation. Recommendations are made for widespread investigation to evaluate the over-all advantages of this new type of insulation.

THE aging of insulating materials is an important factor in the life of electric machines. It is the organic components which age and therefore the deterioration of class-*B* insulation is largely determined by the bonds and varnish rather than by the inorganic components, which have indefinite life. Arnold and Frost[1] indicate that insulating varnish is the most important factor from the standpoint of insulation aging. The permissible operating temperature limits[2] imply this as they permit only a 20-degree-centigrade increase in observable temperature for class *B* over class *A* when inorganic materials such as mica, asbestos, and fiber glass are used in combination with organic resins.

Very early in the development of electric machinery the relation between the life of machine insulation and the operating temperature was recognized. In 1898 discussions of this occurred in meetings of the AIEE.[3] In 1913 Lamme and Steinmetz[4] said, "The problem of permissible temperature limits in electric apparatus is largely that of durability of the insulation" and proposed the idea of a curve expressing the life of insulation. Subsequent studies of the aging of insulation modified opinions as to the shape of the life curve and Montsinger[5] suggested a general law for insulation life. An investigation reported by Scott and Thompson[6] showed that the mechanical durability of class *A* insulation is a function of temperature aging. Their results correlate the law suggested by Montsinger[5] in the range of 135 to 200 degrees centigrade where they report that on two different types of class-*A* windings a temperature increment of 10 to 11 degrees centigrade reduced the time to failure to half.

These early studies and most subsequent investigations of the life of insulation were based on the mechanical durability of insulation. However, they did not emphasize the fact that the thermal behavior of insulation is doubly important because of the effect of aging on moisture resistance. The term "insulation life" implies that after a certain period of aging the useful life of the insulation is expended or that there is a fairly definite end point. However, life is a variable thing and it is preferable to consider that the actual value of insulation life in the laboratory depends on the tests or criteria used to determine the end point. Likewise, service conditions determine the life in normal operation. The use of very severe tests, or severe operating conditions, will result in a minimum life which may be only a fraction of the maximum-life end point obtained by less rigorous conditions. Since one of the most important functions of an insulating varnish is to exclude moisture from the electric windings, it is the opinion of the authors that minimum life of a varnish film may be taken as the point at which a hazardous reduction in moisture resistance occurs.

This general line of reasoning has been applied to the development and evaluation of a totally new group of insulating varnishes, known as silicones. The first silicone varnishes made in the laboratory exhibited remarkable heat stability and waterproofness when compared to organic varnishes. However, it was found necessary to modify the original resins to suit them to the handling requirements of electric-machinery manufacture, and to develop new silicone resins for use in different types of insulation. In this development it was imperative to retain the heat stability and moistureproofness of the original silicones, and therefore it was necessary to have tests which would evaluate these properties.

It is the purpose of this paper to give a brief account of the development of the materials known as silicones, a description of their properties as applied to electrical insulating problems, and a report on some of the results obtained to date and on the work now in progress.

Development of Silicones

Silicones as a new class of high polymeric materials[7] resulted from fundamental research in the field of polymer chemistry bounded by the glasses and

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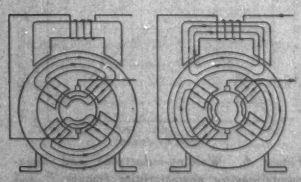
welding sets has placed a new emphasis on the desirability of external reactors.

There is a particular kind of inductance, termed "welding inductance" in this paper, which is effective in producing desired welding characteristics. This inductance, defined as the rate of change of flux linkages per change in current, may be calculated by graphical means and measured from oscillographic tests.

Through study of performance requirements and the function of inductance in stabilizing welding arcs, synthesized reactor designs take full advantage of electromagnetic material. They are thus "tailored" to the requirements of the user through the elimination of unused and unuseful weight.



Figures 7 and 8. New arc-welding reactor mounted on Bergmans split-pole generator showing flux conditions for open circuit (Figure 7, left) and short circuit (Figure 8, right)

Nomenclature

L_w = welding inductance, henrys
I = current, amperes
ϕ = flux, webers
t = time, seconds
E_s = search-coil voltage (at time t), volts
W = energy, joules
N = number of turns
A = area of magnetic circuit, square inches
l = length of magnetic circuit, inches
G = effective air gap, inches

$$= \text{air gap} \times \frac{\text{area of magnetic circuit}}{\text{effective area of air gap}}$$

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1. A New System for D-C Arc Welding, S. R. Bergman. AIEE Transactions, volume 50, 1931, pages 678-80.

2. Some Aspects of Inductance When Iron Is Present, L. T. Rader, E. C. Litscher. AIEE Transactions, volume 63, 1944, March section, pages 133-9.

silicates on the one hand and by the organic plastics on the other. Interest was stimulated by the development of fibrous glass for electrical insulation, since insulating resins and varnishes of a high order of heat resistance were needed before the maximum advantage could be taken of the thermal stability of fiber glass. It soon became apparent that silicones were natural complements to glass, mica, and asbestos in bonding, filling voids, and excluding moisture.

Silicones are derived from sand, brine, coal, and oil as ultimate-source materials. However, like certain of the organic high polymers which are said to come from coal, air, and water, their synthesis involves a number of steps and a considerable amount of industrial and chemical technology as indicated in Figure 1. Sand provides the source of silicon and when heated with coke from coal and chlorine from brine, forms silicon tetrachloride. Organic chlorides, made from hydrocarbons derived from coal and oil by treatment with chlorine from brine are attached to silicon through the use of magnesium metal, also from brine. This reaction[5] replaces one or more chlorine atoms in silicon tetrachloride with a hydrocarbon radical as shown in Figure 1 to produce a variety of organo-silicon chlorides. These are then treated with water to remove all the chlorine and by-product magnesium chloride. The silanols so formed condense with each other to build up large molecules in a manner similar to the hardening of a silicic acid gel or the setting of a phenol-formaldehyde resin.

Liquid Silicones

One of the first groups of silicone polymers to reach commercial production was the liquid silicones. Several families of these silicone fluids are now available in a wide range of viscosities. They are characterized in general by the properties of low change of viscosity with temperature, low freezing point, unusual inertness, and stability to heat. The silicone fluids are finding application as gauge liquids, damping fluids, and in various hydraulic applications. An interesting application is the use of a dilute solution of silicone fluid for treating ceramic surfaces to render them water repellent.

Liquid silicones fall into two groups based on the range of viscosity and service temperature to be covered. Fluids for use down to −55 degrees centigrade and below are listed in Table I for one type covering viscosity grades up to 100 centistokes. The viscosity grades above 20 centistokes are nonvolatile and useful as liquid dielectrics. Their temperature coefficient of viscosity is very low. Fluids for use down to −40 degrees centigrade and up to 200 degrees centigrade are listed in Table II for another type of fluid silicones covering viscosity grades from 100 centistokes upward. All viscosity grades in this type are nonvolatile-liquid dielectrics with an even lower rate of viscosity change with temperature than the lighter-viscosity fluids of Table I. The liquid silicones in Tables I and II are further characterized by their heat stability, their general inertness, and oxidation resistance. They are noncorrosive to metals and are nonsolvents for rubber, synthetics, and other organic plastics. Their flash points are considerably higher than petroleum oils of equivalent viscosity and they will burn, when once ignited, to form silica, carbon dioxide, and water. Their surface tension is low, about 20 dynes per centimeter, and they readily wet clean, dry surfaces of glass, ceramics, and metals, making them water repellent. They are insoluble in water, and are unaffected by water, dilute acids, or salt solutions. They are soluble in most organic solvents including carbon tetrachloride and aromatic naphthas, but are insoluble in alcohol and acetone.

The dielectric constants of the nonvolatile types of the silicone fluids listed range from 2.7 to 2.8 at room temperature depending on the viscosity grade. The dielectric constant of these fluids decreases with increase in temperature. The change is about that which would be expected from the expansion data from Tables I and II. The dielectric constant of liquid silicones changes very little with frequency as shown in Table III. The power factors of these fluids are unusually low, being less than 0.0001 at ordinary frequencies. They do not increase appreciably with increased frequency up to 10^7 and 10^8 cycles as the data of Table III show. At higher frequencies, there is evidence of a more rapid rise in power factor. The power factor increases with temperature but remains lower than a typical transformer oil. Their dielectric strength at 60 cycles is 250–300 volts per mil at 100 mils. Their volume resistivity is in the order of 10^{14} and does not drop below 10^{12} at 200 degrees centigrade. The low dissipation factors of these liquid silicones at elevated temperatures or at high frequencies and their inertness to moisture indicate them for use in liquid-filled capacitors.

Silicone Greases

A translucent silicone grease having a consistency like petroleum jelly has been developed for use as a lubricant for ignition cables to reduce corona cutting of the insulation and permit easy wiring of ignition harnesses. It is stable to heat and retains the consistency of a soft grease from −40 to 200 degrees centigrade. Although it is a soft grease in appearance, it has the unusual property of not melting on exposure to heat. This material also is inert and oxidation resistant. It has no solvent effect upon synthetic insulations

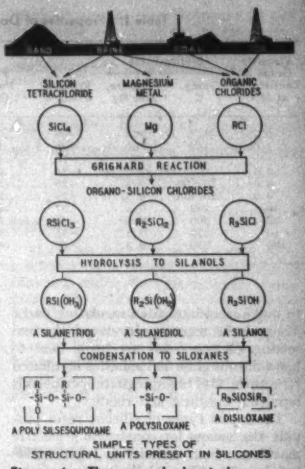

Figure 1. The general chemical processes for the formation of silicones from sand, brine, coal, and oil

or rubber, and tends to prevent the hardening of these materials when heated in contact with air.

Other greases under development are being used for lubricating ball and roller bearings. One type can be used at temperatures as low as −60 degrees Fahrenheit and has high-temperature stability at least as good as the best available organic greases. Another type of silicone lubricating grease is showing stability in ball bearings several times as great as organic greases at the same temperature.

Silicone Resins

Silicone resins are available in two principal types. The first is the insulating-varnish type, which is comparable in physical properties to organic oleoresinous varnishes. The baking temperatures required to cure the currently available silicone varnishes are sufficiently high (200–250 degrees centigrade) to prohibit their use on organic materials; whereas organic varnishes may be used to coat cotton, paper, silk, or wood, silicone varnishes must be used with inorganic materials, such as glass fiber, asbestos, mica, or ceramics. The silicone varnish is used to coat glass-served magnet wire and fiber-glass cloth, and is used as a binder for building up flexible mica-glass laminated sheet. It is also used as the final impregnating and coating varnish to bind together the individual machine components and waterproof the complete assembly.

The second type of silicone resin corresponds in general behavior to the organic thermosetting resins normally used

Table I. Properties of Dow Corning Type-500 Fluid

Viscosity Grade in Centistokes at 25 C	Boiling Point		Freezing Point, C	Flash Point, F (Min)	Sp Gr at 25 C/25 C	Refractive Index at 25 C	Expansion Coef, C×10⁴ per C, 25 to 100 C
	Temp, C	Pressure, Mm Hg					
0.65	99.5	760	−68	30	0.7606	1.3748	1.598
1.0	152	760	−86	100	0.8182	1.3822	1.451
1.5	192	760	−76	160	0.8516	1.3872	1.312
2.0	230	760	−84	195	0.8710	1.3902	1.247
3.0	70–100	0.5	−70	225	0.896	1.394	1.170
5.0	120–160	0.5	−70	270	0.918	1.397	1.095
10	200	0.5	−67	350	0.940	1.399	1.035
20	200	0.5	−60	520	0.950	1.400	1.025
50	250	0.5	−55	540	0.955	1.402	1.000
100	250	0.5	−55	600	0.966	1.403	0.994

to make rigid laminated insulating parts. These more recently developed thermosetting silicone resins are being used to bond fibrous glass and asbestos laminated structures, and to impregnate special coils requiring hardness and rigidity.

These two types of silicone resin provide the means for constructing electric machines which contain no organic materials. The thermal limitations of the complete insulation may be raised to such an extent that thermal aging of the insulation can be ignored in the design process. Factors other than insulation aging will then ordinarily establish the normal operating temperature of the machine at a point well below the temperatures which could be permitted if silicone insulation were used.

Typical Material Tests

Numerous laboratory tests have been made comparing the thermal endurance of silicone resins with many of the organic resins. The most common test is for flexing life on metal panels. This test corresponds to the ASTM "heat endurance" test for varnishes[3] except that elevated temperatures are used. For the tests reported a film 0.002 inch thick is coated on each side of an aluminum panel 0.005 inch thick. After aging at temperature, the end point is determined by bending around a definite mandrel (one-eighth inch diameter is standard).

The results of a series of tests to determine the flexibility life for a silicone resin and for one of the better organic synthetic resin (phenolic alkyd) varnishes are shown in Figure 2. These tests clearly indicate the different order of magnitude of the thermal endurance of the silicone resin. It is of particular interest to note the tests indicate that the life follows the general form of law suggested by Montsinger.[4] This is of considerable significance if it can be demonstrated that the life of insulation on apparatus follows the same law over a wide spread in temperature as it will permit extrapolation of highly accelerated thermal-aging-test data.

Tests on Stator Coils

Tests on sample a-c stator coils show comparable results to those on materials and varnish films. A typical series of tests compares standard class-*B* stator coils and similar silicone-insulated coils which are identical in all respects except the bonding resins, impregnating varnish, and surface film. The coils use glass-insulated wire, glass-backed mica wrapper on the slot section, glass-backed mica tape on the diamonds, and are taped all over with glass tape. In the series of tests reported in Figure 3 the moisture resistance of the two groups of coils is compared during aging at 200 degrees centigrade in air. The initial insulation resistances as well as the values after aging were determined with the coils half immersed in tap water. The values were all measured with a 500-volt d-c megohm bridge one minute after voltage application after one hour in water. The curve clearly indicates the considerable improvement obtained in thermal endurance of the moisture resistance through the substitution of silicone resins for high-grade phenolic-alkyd resins. The difference in the initial insulation resistance is indicative of the superior moisture resistance of silicone resins.

Tests on Complete Apparatus

The final criterion of insulation life is its ability to endure under actual operating conditions in service. Laboratory tests on insulation specimens are useful for purposes of comparison but correlation between such tests and actual performance is always difficult and often impossible. It therefore appears desirable to parallel laboratory tests on materials with tests on complete apparatus, simulating severe service conditions so far as possible. Such tests should be made at several different temperature conditions so that the temperature slope of the thermal endurance can be established.

Special tests have been devised to provide a common basis for such appraisal of the insulation characteristics of motors

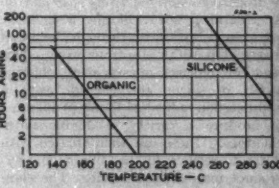

Figure 2. Comparison of the heat endurance of organic and silicone varnishes

Aging to the point of flexing failure is shown on aluminum panels for several temperatures

having high-temperature silicone insulation. These tests were drawn up by a group of engineers representing several companies interested in this development. The primary yardstick used in these tests is the moistureproofness of the insulation. The equipment and procedure for these humidity tests are detailed in the appendix. Windings are exposed to humidity (usually for 24 hours) to determine their resistance to moisture both initially as a bench mark and after some degree of accelerated aging or other damaging test.

To establish the initial condition for a bench mark the windings are humidified by this method for 24 hours and the insulation resistance is then measured be-

Table II. Properties of Dow Corning Type-200 Fluid

Viscosity Grade in Centistokes at 25 C	Flash Point, F (Min)	Sp Gr at 25 C/25 C	Lbs/Gal at 25 C	Refractive Index at 25 C	Expansion Coef C×10⁴ Per Deg C		Viscosity in Centistokes at		
					−25 to 0 C	25 to 100 C	−40 F	100 F	210 F
100	600	0.968	8.08	1.4030	0.926	0.969	650	82	32
200	615	0.971	8.10	1.4031	0.921	0.968	1,300	160	65
350	625	0.972	8.11	1.4032	0.917	0.966	1,950	260	135
500	625	0.972	8.11	1.4033	0.909	0.965	3,300	370	100
1,000	640	0.973	8.12	1.4035	0.900	0.963	6,500	735	260

tween winding and frame. Immediately thereafter a five-minute high-potential test is applied between winding and frame using a test-voltage value the same as the rated line-to-line voltage of the machine. Finally, the machine is operated at normal voltage with no load for five minutes.

As a damaging test of thermal endurance it has been recommended that motors be operated at 240 degrees centigrade as observed by resistance of the winding. The motor should be shut down at least once a day to permit thermal cycling. At periods of 200 hours elapsed time (at temperature) the humidity test should be made to include taking insulation resistance data, five-minute high-potential test, and five-minute no-load run. Where similar tests are to be made at different temperatures to explore the slope of the temperature-aging curve, it is suggested that the length of the running period between humidity tests be halved for each 12-degree centigrade increase or doubled for each 12-degree centigrade decrease in observed temperature by resistance. Such tests are now underway by several investigators comparing silicone and standard insulations. It is suggested by the authors that experimental data from these tests be discussed before the Institute as the data become available to permit rapid evaluation of silicone types of insulation.

Conclusions

It is important to recognize that the use of silicone resins in electrical insulation need not represent any radical departures from well-established practices. Inorganic components of high-temperature insulation have long been available and their characteristics proved. It was the organic bonds, impregnants, and surface treatments which limited the thermal endurance of composite insulation containing mica, asbestos, and fibrous glass. References made in this paper to silicone insulation imply the substitution of silicone resins for all the organic resins in the better grades of class-*B* insulation and do not refer to the use of silicone resins as mica substitutes in any way.

Innumerable tests in the laboratory and over 50 years of service experience have demonstrated that thermal aging is the most important single factor in insulation life. Only after such aging occurs does good insulation become vulnerable to the other ills which plague it. Differences in the thermal endurance of various types of insulation have been clearly demonstrated to be a function of the stability of their essential components. Therefore, the recent development of silicone resins promises great improvement in thermal stability of insulation for electric machines as it improves the weakest link in the insulation system. This improvement properly utilized by designers can be a great asset to the industry. There is no point in increasing operating temperature unless some useful economic purpose is served, but where electric machinery must operate at elevated temperatures silicone resins and high-temperature insulation offer a solution to a previously unsolved problem.

Silicone resins have been demonstrated to have thermal stability far beyond that of the best of the conventional organic materials. It therefore appears timely to re-examine the thermal endurance requirements for insulation of electric machinery, to evaluate the possibile advantages from the use of these more heat-resistant materials, and to seek means for utilizing them for the improvement of electric machinery where their use is justified. These general problems should be investigated and tests made by as many interested engineers as possible so that a broad perspective may be obtained promptly.

Table III. Dielectric Properties of Typical Dow Corning Silicone Fluids

(At 25 C and 50 Per Cent Relative Humidity)

	3 Centistokes, Type 500		350 Centistokes, Type 200	
Frequency, Cycles	Dielectric Constant	Power Factor	Dielectric Constant	Power Factor
10^3	2.412	0.0001	2.74	0.0001
10^4	2.41	0.0001	2.73	0.0001
10^5	2.405	0.0002	2.72	0.0002
10^6	2.40	0.0002	2.71	0.0002
10^8	2.39	0.0002	2.70	0.0006

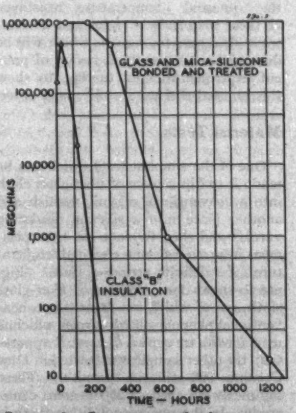

Figure 3. Comparison of the moisture resistance of class-*B* and silicone-treated insulations on typical a-c generator coils during aging at 200 degrees centigrade

Insulation resistance values were taken after one hour immersion in tap water for each point

Appendix. Proposed Equipment and Procedure for Standardized Humidity Test

Equipment

The apparatus to be tested is enclosed in a suitable box or moisture-vapor barrier so that it is within the high-humidity atmosphere. The top should be slanting or peaked (or otherwise arranged) so that condensate does not drip on the winding. It is desirable that the sides of the box have thermal insulation and that the top of the box be uninsulated. An open pan of water within the enclosure is heated electrically to humidify the enclosed air.

Procedure

The relative humidity is maintained at 100 per cent by heating the open pan of water within the enclosure to five or ten degrees centigrade above the ambient air temperature in the enclosure. This should be sufficient to produce minute droplet condensate on the frame and insulation surfaces of the apparatus. However, it must not produce sufficiently severe condensation to form puddles or streams of water on the insulation. The test equipment should preferably be located in a room whose ambient temperature is between 25 and 30 degrees centigrade. Apparatus not open for the free circulation of air must have one end bracket removed to permit free access of the humidified air to all parts of the winding.

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The Application of Silicone Resins to Insulation for Electric Machinery

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Synopsis: Experience with the application of silicone resins is described, including laboratory tests on materials and coils, as well as laboratory tests on rotating apparatus. Practical problems regarding the use of these materials are discussed and recommendations made for obtaining an adequate high-temperature insulation. Thermal aging tests are reported and recommendations made as to tentative temperature limits for general rating and application purposes.

THE thermal endurance of insulation has long been recognized as an important limiting factor in electric-machine design. The investigations of numerous engineers[1,2] and the electrical-industry standards[3] have clearly indicated that operating temperature is the determining factor for insulation thermal endurance and is, therefore, the primary basis for establishing general machine ratings. It must be recognized, however, that there are frequently other design considerations which outweigh temperature limitation.

The advent of silicone resins is an important milestone in insulation development as these resins in combination with inorganic insulations such as mica, asbestos, and fiber glass have unusually high thermal endurance. It appears that designers may utilize this excellent temperature resistance in three important ways, when permitted by AIEE Standards:

1. To reduce size and weight of some apparatus through increase in operating temperature.

2. To permit operation in a high ambient temperature.

3. To obtain increased insulation service life or reliability where it is desired to maintain conventional size, weight, and temperature.

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The authors gratefully acknowledge the co-operative work of numerous members of the Dow Corning organization which made this development possible. In addition, acknowledgment is made for continued interest and helpful guidance of Messrs. R. C. Bergvall, J. G. Ford, C. F. Hill, and J. Swiss, all of the Westinghouse Electric and Manufacturing Company.

Silicone-Resin Development

Recent developments have made possible the production of a new class of materials known as silicones having certain unusual properties which are of vital interest to the electrical industry. Some silicone materials have physical properties which are comparable to conventional organic materials such as varnishes, oils, greases, plastic resins, and film-forming materials. They are, however, characterized by a chemical structure in which silicon takes the place of carbon in certain portions of the molecule. They have mechanical and electrical stability when exposed to elevated temperature. Based upon recent work by the Dow Corning Corporation, it is now apparent that the silicone materials can be produced so that they duplicate many of the better known organic materials with respect to most physical properties. Silicones can be "tailor made" for specific applications in the same way that organic compounds have been developed in the past. Since the unusual temperature resistance of these materials is of interest to electrical designers for reasons which will be discussed subsequently, a review of present experimental data tending to show this unusual thermal stability is in order.

Material Tests

One of the simplest tests which can be made is to dip a piece of fiber-glass cloth into a conventional organic varnish and another piece into a silicone insulating varnish and then to place the two specimens in an oven at some elevated temperature for a definite period of time. Figure 1 shows two samples of fiber-glass cloth, one of which was treated in a conventional phenolic-alkyd varnish which is used for the treatment of class *B* apparatus; the other sample was treated in Dow Corning 993 silicone varnish. These samples were aged at 250 degrees centigrade. In the unaged condition there is very little difference in the mechanical properties of the two samples. They are both good electrical insulators, are not seriously affected by immersion in transformer oil, and are quite moisture resistant. After only two hours' aging, the sample which was treated in organic varnish was seriously affected and after 20 hours' aging had completely deteriorated and under no circumstances could be considered as a dielectric material, while the silicone-treated sample had undergone no observable deterioration.

A more quantitative evaluation of the relative thermal stability of conventional organic varnishes and silicone varnish can be obtained by making the standard ASTM flexing life test (frequently called heat endurance) for insulating varnishes. It has been found that the use of copper panels as recommended by ASTM is not satisfactory since the copper is prone to rapid oxidation and it is desirable to substitute either cadmium plated copper or aluminum for the test panels. Figure 2 shows the relative ASTM flexing life of a conventional phenolic-alkyd varnish and one of the silicone varnishes. It is well known that these flexing life tests do not indicate the point at which varnish films would fail on an electric machine, but they are useful for comparing the relative order of magnitude of heat endurance. The end point of this test corresponds roughly to a 14 per cent elongation of the film. It is of interest to examine the rate at which the maximum elongation for failure changes with time and temperature. Figure 3 gives the percentage elongation for failure ont he modified ASTM flexing life test plotted against the number of hours aging. At 200 degrees centigrade a good phenolic-alkyd organic varnish will last about two hours before failure occurs at 14 per cent elongation. One silicone varnish under the same condition will last about 1,000 hours. At seven per cent elongation and 200 degrees centigrade the organic varnish will last about 40 hours while the silicone varnish will last about 1,500 hours. These data indicate that at the same temperature, the silicone varnish may last from 40 to 500 times as long as an organic varnish.

A very sensitive test on the relative thermal stability of two materials can be made by coating copper wire with the resins and making elongation tests at periodic intervals after aging at elevated temperature. Figure 4 gives a detailed comparison between a wire enameled with an oleoresinous varnish, a synthetic organic resin enamel, and one of the silicone insulating varnishes. At 150 degrees centigrade the silicone-enameled wire was aged for 6,964 hours before it failed at an elongation of nine per cent while the synthetic-organic-resin-insulated wire failed at a nine per cent elongation after only 240 hours. At 200 degrees centigrade the synthetic-organic-resin-insulated wire failed at an elongation of three per cent in two hours while the silicone-insulated wire was aged for 216 hours before failure at the same elongation.

A critical analysis of all the relative data on aging of organic materials and silicone materials leads to the conclusion that the silicones are highly stable with respect to thermal aging; however, since

Figure 1. Samples of fiber-glass cloth coated with organic resin and silicone resin varnishes showing effect of aging at 250 degrees centigrade

the rate of deterioration with respect to different temperatures is not a constant factor for either the organic materials or the silicone materials, it is necessary to compare the two at a specific temperature if a comparison of their relative heat stability is to be made. It is the opinion of the authors that silicone varnishes which are now available will protect electric apparatus for 20 to 100 times as long as conventional organic materials at the same temperature, or to put the matter another way, operating temperatures may be raised 50 to 75 degrees centigrade when these resins are used.

Since the silicone resins are characterized by extreme heat stability, it would be reasonable to suppose that they would also require higher temperatures for drying and processing. At the present time this is the case for most of these. It has been found that electric machines insulated with silicone varnishes must be baked at temperatures from 200 to 250 degrees centigrade for times which are comparable to standard processes using organic varnishes. There is some indication, from recent experimental work, that this condition will not always exist.

Tests on moisture permeability using a Payne cup indicate that the moisture transmission through films of cured silicone varnishes is comparable to that obtained through the better grades of organic insulating varnishes and materials such as soft vulcanized rubber, molded phenolics, or asphalt sealing compounds. These tests might lead to the belief that very little improvement in the moisture resistance of electric machines could be obtained by using silicone insulation. Actual tests on insulated coils, however, indicate that silicone-insulated coils maintain their insulation resistance under high-humidity conditions for a much longer period of time than do coils insulated with organic varnishes.

High-Temperature Insulating Materials

Extensive tests have indicated that materials deteriorate under the influence of heat due to two effects which are apparently independent of each other and differ in relative magnitude depending on the specific materials. One of these effects is caused by oxidation and can be prevented to a certain extent by minimizing the presence of oxygen. The second effect, sometimes called thermal decomposition, is primarily a function of time and temperature. Since most conventional organic materials show rapid thermal deterioration below the processing temperatures for silicone resins, it is desirable that all such materials be eliminated from the coils, filling strips, wedges, and other insulating structures of a machine. Therefore, it has been necessary to develop a complete line of insulating materials based on silicone resins which replace the conventional materials containing organic matter susceptible to thermal decomposition. Silicone-varnished-glass cloth, silicone–glass–mica wrappers, silicone–glass-covered wire, silicone filling cements, silicone–glass–mica tape, silicone-sized glass tape, and silicone-treated asbestos cloth have been developed for limited use in high-temperature insulated machines. In certain cases it is difficult to eliminate thin layers of tissue paper on composite mica insulation and before processing in silicone varnish, it is desirable to prebake apparatus to eliminate the volatile portions of such organic material.

Heat, Vibration, and Expansion Tests on Coils

Tests were run on armature coils with three different types of class *B* insulation in comparison with high-temperature-silicone insulation. These were wound into a core and subjected to severe vibration and thermal cycling in combination with accelerated thermal aging. The coils were typical d-c generator armature coils and each coil consisted of two single coils per slot composed of four strands of 0.114 by 0.229-inch copper ribbon. All groups had mica ground insulation, but numbers 2 and 4 used glass-backed mica. Groups 1 and 3 were finished with asbestos tape and were treated with a high-grade organic thermosetting varnish and groups 2 and 4 with glass tape. Groups 1, 2, and 3 were treated with thermosetting varnish and group 4 with silicone varnish. There were nine coils from each group wound in a core as shown in Figure 5. A fractional-horsepower high-speed motor operated on an unbalanced flywheel to provide severe vibration. All the coils were connected in series and energized through a cycle drum and a timer so that the coils were heated for 12 minutes and cooled by a blower for 18 minutes. The test ran 16 hours a day for 36 days, during which the coil temperatures were between 209 and 230 degrees centigrade. The asbestos finishing tape in groups 1 and 3 showed serious thermal deterioration and the glass tape in group 2 became hard and brittle, while the glass finishing tape of group 4 (high-temperature-silicone insulated) was still soft and flexible. Mica treated with silicone resin retained considerable more flexibility than the class-*B* mica insulation. The glass-covered conductor insulation was in usable condition on both groups 2 and 4 but the insulation on the wire with silicone treatment had better flexibility than that treated with organic resin.

Thermal Aging Test of Totally Enclosed Induction Motor

It is believed that the first motor successfully treated with silicone resins was a totally enclosed fan-cooled induction motor on which tests were started early in April 1942. For this test it was designed for ten horsepower, three phases, 60 cycles, 440 volts, four poles, 1,690 rpm. It was insulated with the best available grade of class-*B* insulating materials using glass and mica and the finished winding treated with silicone varnish. (Composite high-temperature-silicone insulating materials were not used as at that time they were not available.)

Summary of Tests

1. Complete engineering tests were made including full-load temperature run at rated horsepower (100 degrees centigrade rise by thermocouple).

2. The motor was overloaded, the temperature reaching 416 degrees centigrade in $1\frac{1}{2}$ hours.

3. The load was reduced until the temperature stabilized at 300 degrees centigrade.

4. The motor was heavily overloaded for a

period of 45 minutes, the temperature of the windings reaching 506 degrees centigrade.

5. After the foregoing tests the motor was retreated and then given a thermal endurance test at a load producing 210 degrees centigrade rise by resistance. This test continued for a total of 3,376 hours at an estimated hot-spot temperature of approximately 250 degrees centigrade.

6. Periodically the motor was dismantled for examination and exposed to high humidity and various insulation tests.

Detail Discussion

After thermal endurance test of 920 hours the silicone-varnish treatment was in generally good condition. The windings stood high-potential and high-frequency tests at 2,000 volts, insulation-resistance tests, and high-potential tests after exposure to humidity without failure. After a severe humidity test with end bells removed, the insulation resistance was reduced but was adequate for operation. The motor was again examined and given humidity and insulation resistance tests after 2,250 hours aging. The varnish showed slight signs of deterioration but remained reasonably good. After 3,376 hours of operating on the accelerated aging test the motor stalled due to bearing failure. The rotor conductors melted and flowed over the windings as is shown in Figure 6. The silicone varnish and insulation were in relatively the same conditions as when last examined. It was evident that the bearing was the cause of failure. On the basis of this evidence it may be concluded that the winding and insulation were suitable for further operation. To examine the condition of the insulation, the motor was stripped. The resin was found to be brittle and to powder as the winding was stripped. At places the glass tape in the end windings broke easily. Loosening of the glass was more frequent in the end windings than in the slots, but glass-backed mica cells were still solid and flexible to a considerable degree. In most places the glass wire covering still retained adhesion to the conductors. It must be recognized that in this first silicone-treated motor other resins and bonds were used, the silicone varnish being used only for final treatments.

Thermal Aging Test of Medium-Size Three-Phase Generator

The stator winding of this generator was completely insulated with high-temperature-silicone insulation. This included silicone resins for treatment of the glass-covered wire, mica bond, treatment of glass cloth and tape, impregnation of the coils, and surface dipping of the wound stator. All ground insulation was glass-backed mica wrapper or tape. Treated glass was used only as a separator or binder. Slot wedges were of the best available grade of phenolic-bonded asbestos laminate plus a few made of phenolic-bonded glass cloth.

Water-Spray Test

An initial water spray was made to check the moisture resistance of the winding. During a 48-hour spray test the insulation resistance (one-minute value) of the winding fell from 28,000 megohms to 2,600 megohms.

Thermal Aging Tests

While heating the stator, the generator was driven at normal speed with the stator winding short-circuited. Field current was adjusted to produce a stator current of $2^1/_2$ times normal, resulting in approximately 210 degrees centigrade rise by resistance. Thermal cycling of the winding was obtained by operating the stator on short circuit on alternate days only. At other times the stator was operated on open circuit with the field overexcited. This resulted in approximately 40 per cent above normal voltage being generated in the stator winding producing the effect of overpotential test on turn and ground insulation. A further purpose was to provide thermal cycling of the windings on these alternate days.

The following temperatures in degrees centigrade were observed on the stator and are representative:

Ambient air temperature	25
Winding rise (by resistance)	211
Core rise (by thermometer)	94
Frame rise (by thermometer)	42
Outgoing air rise (by thermometer)	69

Periodically during the thermal aging test the machine was examined. The visual aging of the outer varnish film was very slight during the whole test. The machine operated for 2,966 hours with the stator winding at the conditions previously described. Based on 211 degrees centigrade rise by resistance with a 25-degree-centigrade ambient temperature and a 15-degree-centigrade hot-spot allowance, this is equal to approximately 250 degrees centigrade hot-spot temperature. At the end of this thermal aging test the winding was humidified, by maintaining exposed water surfaces heated above the ambient temperature in an enclosure. The generator was covered with a double thickness of waterproof paper and a tarpaulin. Water was evaporated at the rate of approximately three quarter gallon per 24 hours within this enclosure and the following values of insulation resistance observed:

Time of Humidification	Stator Winding Megohms (One-Minute Value)
Start	4,900
3 days	2,800
16 days	1,300
19 days	380

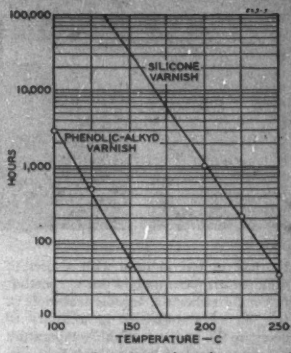

Figure 3. Comparison by elongation of silicone varnish film 0.002-inch thick and organic varnish film 0.002-inch thick after thermal aging

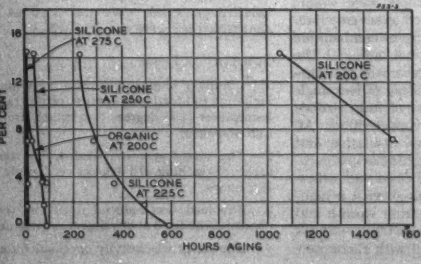

Figure 2. Comparison of flexing life of 0.002-inch-thick films of organic resin and silicone varnishes on copper panels aged at various temperatures

Final Insulation Tests

Immediately upon completion of the final humidification test a series of tests was made on the stator winding (without dryout) as follows:

1. High-potential test to ground at 1.4 times rated voltage (60 cycles) for five minutes.

2. Operation open-circuited at normal speed with maximum field excitation (40 per cent overvoltage) for one hour.

3. Short circuit applied to stator terminals with field excitation set for normal open-circuit voltage. Applied for two minutes, with no evidence of loosening of winding.

4. Insulation resistance—10,200 megohms; dissipation factor—3.2 per cent.

5. Intentional destruction by high-potential test (without drying out winding). Held 1,000 volts and failed at 1,800 volts in 12 seconds. (Rated operating alternating voltage = 440 volts.)

Laboratory Tests on General-Purpose Induction Motors

Numerous totally enclosed fan-cooled induction motors have been made using high-temperature-silicone insulation and subjected to operation at high temperature. None of these motors as yet show any marked deterioration of the insulation as indicated by insulation-resistance readings and all motors have been subjected to high-potential tests with no breakdowns. The motors listed in Table I with the operating temperature and time of operation up to date were still under test at the time of preparation of this paper.

The table indicates that the use of silicone varnish and materials will make it possible to operate electric apparatus at a higher temperature than has been used previously. It must be recognized that in the use of higher operating temperatures, other problems must be studied. Air gaps may have to be larger to allow for more expansion of the rotor, bearings will have to allow for more shaft expansion, and bearings and lubricants must operate at higher temperatures.

High-Temperature Lubricants

From the standpoint of machine construction and operation, it is obvious that if the greater temperature stability of silicone resins and insulating materials is to be utilized it is necessary on certain apparatus to obtain lubricants which will function at higher temperatures. The development of silicone oils and greases has advanced to the point where it appears that these materials enjoy the same superiority over organic lubricants as silicone varnishes enjoy over organic varnishes. Tests on actual motors have

Table I

Motor (Hp)	Winding Temperature (Deg C)	Hours
2	170	3,480
2	185	3,486
4	140	3,996
4	160	3,996
7½	320	1,907
7½	320	1,907
15	185	3,506
15	170	3,506
25	160	3,291
25	135	3,291
0	285	4,500
10	250	3,400
10	250	3,400
25	240	3,300
10	300	5,200
10	185	3,200

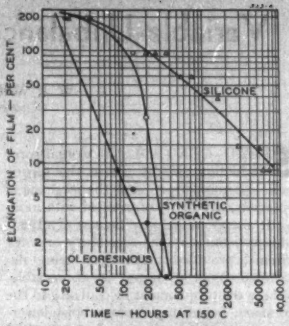

Figure 4. Elongation failure versus time for resin films on number 18 copper wire

indicated that the better grade of organic lubricants cannot be operated for extended periods of time above 90 degrees centigrade. Comparable tests on silicone greases lead to the belief that bearings lubricated with these materials can be operated at about 50 degrees centigrade above conventional limits. Extensive tests are now in progress and it appears likely that machines will be in service which have not only silicone treated and bonded insulation but silicone lubrication as well.

Review of Design Factors

A large number of general-purpose induction motors have been wound using silicone-treated materials and silicone as an impregnating varnish. On open, splashproof, and semienclosed motors where the performance of the motor rather than the temperature determines the amount of material used, the use of high-temperature insulation gives no advantage. The size of these motors is determined by the pull-out torque, starting torque and starting current, efficiency, and power factor and it is found that when the above factors are maintained at values acceptable to the users, the temperature rise is such that present class *B* insulation has sufficient thermal stability to give life comparable to present class-*A*-insulated motors.

Silicone materials may have a use on totally enclosed and totally enclosed fan-cooled motors, as the present allowable temperature limits definitely determine the amount of material used. The design of these motors for maximum use of the electric parts, keeping the performance acceptable as stated above, gives temperatures somewhat in excess of the allowable class *B* temperature. For this type motor, the use of silicone materials with the higher temperatures may be advantageous.

Several totally enclosed and fan-cooled motors have been made and tested experimentally. The performance of these motors is not the ultimate performance as the electric parts used were those currently in use in class-*A*-insulated machines. For a true high-temperature motor for maximum use of the material it will be necessary to change the relation of copper to iron, the quality of the iron, length of air gap, and so forth. Further studies of this problem are now under way.

Special Considerations and Limitations

There has been considerable discussion of some of the limitations of silicone resins; for example, mechanical fragility, low abrasion resistance, and poor oil and solvent resistance. In this connection it must be recognized that there are many of these materials with varying physical characteristics. It is true that some, particularly the early forms, were considerably inferior to the better organic resins in some of these characteristics. However, there is considerable difference between silicone resins in this respect. More recently developed resins have been even better, and are now readily usable. That essential silicone characteristic, thermal stability, tends to make the resins difficult to cure. As a consequence, full physical characteristics, such as abrasion resistance, may not be developed unless proper processing is obtained. In using high-temperature-silicone insulating materials it is important that precautions be taken in every stage of manufacture to develop the essential physical and chemical characteristics of the silicone resins.

The high baking temperatures (usually 200 degrees centigrade to 250 degrees centigrade) necessary for curing silicone resins, in the present state of the art make it imperative that composite insulations contain little if any organic materials. All bonding resins for composite insulations should be silicone and an absolute

Figure 5. Test setup for severe thermal aging, thermal cycling, and vibration test

Figure 6. First silicone-treated motor after bearing failure

Operated 3,376 hours at 250 degrees centigrade hot-spot temperature

minimum of cellulose materials should be used for structural purposes. Before applying silicone treatment, either by impregnation or dipping, the coil or apparatus should be baked out, at a temperature at least equal to the final baking temperature, to drive out all gas from decomposition of organic materials such as is contained in small percentages of cellulose.

It should be recognized that there is much to be learned regarding these new silicone compounds and their application to electric apparatus Furthermore, the high-temperature-silicone insulating materials are available in limited quantities. It, therefore, appears advisable to restrict the use of high-temperature-silicone materials to a few specific applications so that this development will be carried out in an orderly and progressive manner.

Interpretation of Tests

Tests on silicone resins, silicone-treated materials, and wound apparatus treated with silicone varnishes demonstrate that:

1. An unusually high order of thermal endurance is obtained.

2. The materials are usable with relatively minor variations in conventional processes (mainly in baking temperature).

3. That on some types of electric apparatus an appreciable advantage may be obtained in rating through operating at the higher temperatures when such are permitted by AIEE Standards.

Conclusions and Recommendations

Silicone resins and composite high-temperature-silicone insulation materials promise considerable improvement in the thermal endurance of electrical insulation. The exact improvement is difficult to evaluate and will require much additional experience and test work. It is believed conservative to state that the silicone materials with which the authors are familiar have from 50 to 75 degrees centigrade advantage over conventional class *B* insulations.

It is the recommendation of the authors that the availability of this new type of insulation be recognized at once by the assignment of some classification or designation to differentiate it from class *B* and *C*. It is further suggested that a tentative limit be established for this insulation at 40 degrees centigrade above the present observable temperature (by resistance) for class *B*. Furthermore, an increase of five degrees centigrade in hot-spot allowance is suggested. On this basis, it is suggested that the limiting hot-spot temperature for high-temperature-silicone insulation (corresponding to the 130 degrees centigrade limit for class *B* insulation in AIEE Standard 1) be set, at 175 degrees centigrade. It is recognized that certain industries have special standards and that only experience and further tests will demonstrate what their limits should be. It is the opinion of the authors that these recommendations are conservative but that the proposed temperature limits will give designers a significant advantage over class *B* temperature limits.

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Variable-Unbalanced-Voltage Control

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NONMEMBER AIEE

SPEED CONTROL of wound-rotor induction motors where the torque is in the same direction as the mechanical rotation may be accomplished with moderate success merely by the use of adjustable resistance in the secondary or rotor circuit, provided the torque being developed by the motor is appreciable. Where the torque must be contrary to the rotation, for example, crane-hoist lowering, the problem of control at less than synchronous speed becomes much more complex, and special consideration in control design is required. Such refined subsynchronous speed control can be attained, provided the torque is in excess of possibly 35 per cent of full load, by exciting the motor stator with direct current and adjusting rotor resistance in the ordinary way. For those applications where the countertorque is less than 50 per cent normal, or absent altogether, satisfactory speed control is provided by application of adjustable unbalanced polyphase voltage to the motor primary. Neither of these systems is entirely satisfactory for the complete speed–torque range, since the former does not provide low torque at high speeds and the latter does not provide rated torque at slow speeds. Both require considerably greater input current than the motor would require to develop an equivalent countertorque with balanced polyphase voltage applied. It is possible, of course, to control the countertorque in the orthodox manner by an adjustable rotor resistor. This system has been used extensively, but is considered satisfactory only for certain applications involving predetermined loads.

The performance characteristics of the polyphase induction motor, when operating with unbalanced primary voltage, have long been understood, and literature on the subject has appeared from time to time. Reaction to the use of unbalanced voltage generally has been pessimistic because of the associated phenomena of relatively high input current for a given output torque. It is the purpose of this paper to describe briefly a system of control which incorporates a new feature, namely, variable unbalanced primary voltage automatically responsive to speed. Introduction of variable unbalance has made it possible to:

1. Employ unbalanced voltage without the excessive input current which might be expected.

2. Obtain characteristics providing any degree of starting torque from zero to 75 per cent full load without adjustment of rotor resistance.

3. Obtain less than synchronous speed with no load.

4. Obtain characteristics providing re-

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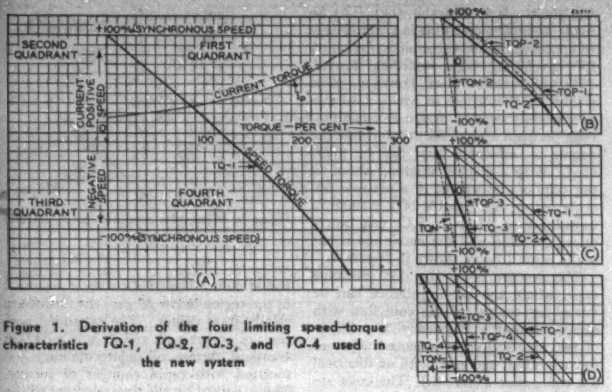

Figure 1. Derivation of the four limiting speed–torque characteristics *TQ*-1, *TQ*-2, *TQ*-3, and *TQ*-4 used in the new system

tarding torques which are zero at zero speed, and which cover a speed range of 0 to 35 per cent at light or no load, and 10 per cent to 150 per cent at full load.

The essential elements of the control system are shown in Figure 10, and include a variable impedance reactor, a phase shifter, and a speed detector with amplifier, in addition to the parts composing a standard reversing controller.

Performance With Unbalanced Voltage

The familiar mental conception of the reactions taking place in an induction motor pictures a single revolving magnetic field on the stator, the rotor following at somewhat lessened speed, with voltage and frequency existing in the rotor windings in proportion to the slip. If the applied polyphase voltage happens to be unbalanced, the revolving field becomes unsymmetrical, that is, it does not have the same magnitude for all positions on the stator. This unsymmetrical field can be analyzed by the method of symmetrical components. By this means this unsymmetrical field can be replaced by two symmetrical fields, one of which revolves in the same direction as the rotor (positive sequence) and the other of which revolves in the opposite direction (negative sequence). The relative magnitude of negative sequence increases with the degree of unbalance. The net output torque of the motor is, of course, the algebraic summation of the component positive- and negative-sequence torques which are developed in the rotor due to the positive- and negative-sequence stator fields.

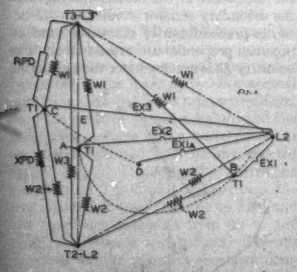

Figure 2. Vector relations for voltages across motor windings *W*1 and *W*2, for the four conditions of unbalance producing the limiting speed–torque characteristics of Figure 1

tarding torque. Curve I_p shows the current input for balanced voltage, corresponding to *TQ*-1.

From the viewpoint of symmetrical components, *TQ*1 may be considered to be the positive-sequence torque component, where the negative-sequence component is zero. The new system uses a minimum unbalance in voltage as caused by the displacement voltage vector *EX*1 in Figure 2, where *EX*1 equals 0.23*E*. For the minimum unbalance illustrated the positive-sequence speed–torque characteristic is shown by curve *TQP*2, and the negative-sequence component by *TQN*2 in Figure 1B. The positive component is quite similar to the positive component *TQ*1 for balanced voltage, except that the magnitude is reduced along the torque axis. The loss in torque is caused by a net reduction in primary voltage (winding *W*1 96 per cent normal and winding *W*2 80 per cent normal).

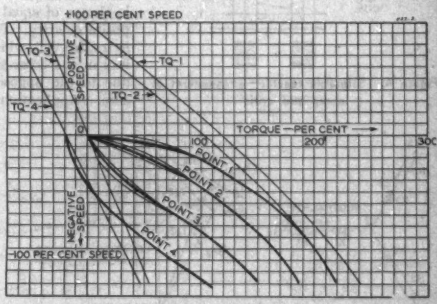

Figure 3. Speed–torque characteristics for motor with speed-responsive variable unbalanced voltage

As the torque changes from 0 to maximum for points 1–2–3, the corresponding unbalance varies as *T*1 moves along the locus from *A* toward *B* in Figure 2. For point 4, *T*1 moves along the locus from *C* toward *D*

High Secondary Resistance—Limited Input Current

A fundamental of the new system, and one of prime importance, consists in the use of a single relatively high value of external rotor resistance for all subsynchronous speed control which will produce the speed–torque characteristic *TQ*-1 in Figure 1A. The curve *TQ*-1 shows that within the operating range in the fourth quadrant the motor operation is stable, that is, an increase in speed is always accompanied by an increase in retarding torque. The negative-sequence component is similar to the positive component, except the magnitude is lower since the unbalance is not great, and it is inverted on the speed axis since the slip for this field is opposite to that for the positive field. The motor shaft torque is the algebraic sum of the two components, or the characteristic *TQ*2.

If the motor primary voltage is further unbalanced by increasing the displacement vector *EX*2 (Figure 2) to 0.866*E*, single phase is essentially applied to the motor. The positive (*TQP*-3) and negative (*TQN*-3) sequence components are equal in magnitude for equal degrees of relative slip, and therefore the shaft torque characteristic *TQ*3 passes through zero torque at zero speed and the shaft torque opposes the rotation at all speeds.

If *EX* is increased in magnitude still further, as shown by *EX*3, the phase sequence at the motor terminals is reversed and the negative-sequence torque component becomes predominant as shown by a comparison of *TQP*-4 and *TQN*-4. The corresponding motor shaft torque passes through zero at minus 35 per cent speed and shows that negative torque is developed at zero speed.

Speed-Responsive Variable Unbalance

The four speed-torque characteristics *TQ*-1, *TQ*-2, *TQ*-3, and *TQ*-4, each resulting from the application of different values of fixed unbalanced voltage and with input current limited, do not cover effectively the area of the fourth quadrant (Figure 3) and are therefore unsuitable in themselves for speed control at all loads. The new system provides the necessary coverage by effecting an automatic transfer in response to speed from either of the characteristics *TQ*-3 or *TQ*-4 at zero speed toward or to the characteristic *TQ*-2 at any selected negative speed. The curves are of the general shape shown in Figure 3. They are quite different, particularly in the low-torque regions, than any speed–torque characteristics heretofore attained. There may be as many intermediate curves as desired, and they may originate from either *TQ*-3 or *TQ*-4 at zero speed.

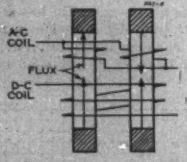

Figure 4. Saturable reactor—arrangement of cores and coils

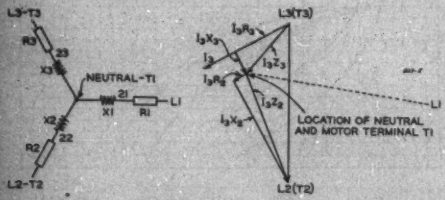

Figure 5. Hypothetical equivalent circuit and vectors for combination consisting of motor windings and the phase shifter *RPD*-*XPD* (Figure 2)

Variable-Impedance Reactor

The vector voltages *EX*1 and *EX*2 and any intermediate value shown between *L*1 and *T*1 in Figure 2 are produced by a single-phase variable-impedance reactor connected between these points. The vector voltage *EX*3 and *EX*1*A* and all intermediate values are produced by the same reactor in combination with a phase shifter. It may be argued that with anything less than infinite impedance, the reactor drop *EX*2 from *L*1 to *T*1 cannot equal 0.866*E*. This is true, but if the impedance in ohms is not less than $0.026E^2$ motor horsepower there is no effective phase rotation at the motor terminals and no torque is developed at the shaft. It is desirable that *EX*1 be made as small as possible in order closely to approach normal three-phase operation for developing high retarding torque. Practical considerations, however, place a limit on the degree to which *EX*1 can be reduced, and the design is a compromise between size of the reactor and the degree of unbalance that can be tolerated. With a reactor weighing about 20 per cent of the weight of a six-pole 60-cycle motor and capable of a change in impedance of 55 to 1, *EX*1 can be reduced to 0.23*E* and the maximum result is the point 1 curve shown in Figure 3.

The reactor is of the d-c saturable type, where the a-c impedance can be varied by control of the core flux with direct current. Physically it consists of two identical cores mounted adjacent to each other, and each with an identical a-c coil. (See Figure 4.) The coils are connected in parallel but in reversed relation such that the flux in the two cores is always of equal magnitude but of opposite polarity. Both cores are enclosed in a third coil, which is unaffected by a-c flux in the cores since their summation, due to the opposite polarity, is always zero. Application of direct current to this third coil introduces undirectional flux and thus reduces the capacity for alternating flux and accordingly the reactance of the a-c coils. The d-c energy required for excitation of the reactor is quite small compared to the a-c energy that may be controlled. Considering the maximum a-c volt-amperes at 100 per cent, the minimum will be eight per cent and the direct current energy to cause this change will be 0–1.5 per cent, for the reactor as designed for this control system. The solid curves in Figure 3 in the region below 50 per cent torque are steady-state values. The expanded portions of curves 1, 2, and 3 show a certain transient degree of indeterminancy associated with rapid changes of torque. This is caused by the time constant of the d-c exciting circuit of the reactor. The motor performance is affected only when low flux densities and the associated slower time response is involved.

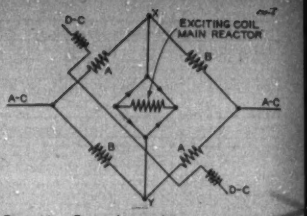

Figure 6. Circuit for amplification of detector output

Phase Shifter

The phase shifter is a series reactor and resistor combination, indicated by *XPD* and *RPD* in Figure 2. As connected, the resistor *RPD* and motor winding *W*1 form one element of a wye-connected three-phase load. The second element is the reactor *XPD* and winding *W*3, and the third is the reactor (voltage drop *EX*3). The neutral of the wye-connected load is therefore the motor terminal *T*1, and the displacement of the neutral with respect to *L*1–*L*2–*L*3 determines the unbalance of voltages applied to the motor windings. Each of the elements contains reactance and resistance, and each may be resolved into hypothetical equivalent circuits per Figure 5, where the three elements are *Z*1, *Z*2, *Z*3. By choice of values for *XPD* and *RPD*, so that the hypothetical impedance of *Z*2 and *Z*3 are about half the hypothetical impedance of the motor winding with the secondary resistor connected, *Z*2 becomes preponderantly reactance, and *Z*3 becomes preponderantly resistance. The quantity *Z*1 is much greater than either *Z*2

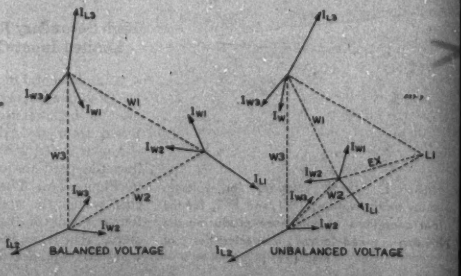

Figure 7. Comparison of balanced- and unbalanced-motor-current vectors

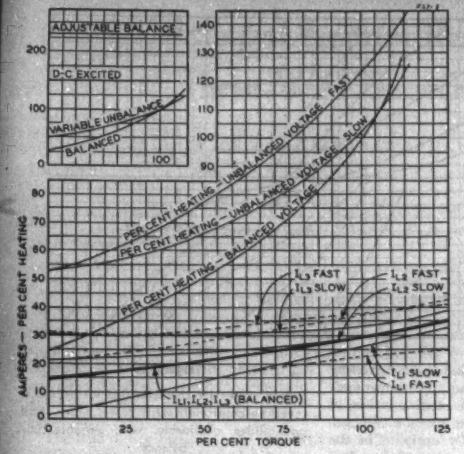

Figure 8. Current input and per cent average heating of the three motor primary windings for ten-horsepower six-pole wound-rotor motor

"Fast" and "slow" refer to speed, and the former is accompanied by high unbalance, the latter by low unbalance when developing a given torque. The insert shows a comparison of average winding heating associated with four different systems of control, when exerting full-load torque at the lowest possible speed

its fundamental frequency. Besides these modulations there is still another variable in the secondary voltage, resulting from the variable unbalance. This variable is indirectly associated with speed in such a way that a rise in speed is accompanied by a rise in secondary voltage, however only in proportion to the torque being developed. Thus as the speed rises from 0 to minus 100 per cent the magnitude of the secondary voltage is largely indeterminate, but its frequency has a perfectly definite value for any speed. The speed detector therefore has been designed for minimum response to magnitude of impressed voltage, and maximum response to the frequency thereof.

The detector itself consists simply of a three-phase transformer operating at high flux density, a capacitor in series with each primary coil, and a rectifier to convert the output to direct current. The impedance of a capacitor varies inversely

or *Z*3 when the reactor is unexcited, therefore its effect on the position of the hypothetical neutral can be neglected, and the approximate location can be determined by a vector analysis of *Z*2 and *Z*3 in series across the voltage *L*2–*L*3. A vector diagram of the component voltages through *Z*2 and *Z*3 appear in Figure 5, showing how the neutral of this system is displaced with respect to the reference voltages *L*1–*L*2–*L*3, to produce the vector *EX*3 shown in Figure 2, and reversed phase sequence.

Speed Detector and Secondary-Voltage Phenomena

Direct current for control of the reactor impedance must vary, not necessarily directly, but at least as a function of motor speed. The source of power for control of this direct current is the motor secondary voltage, and particularly the high-frequency modulations that exist therein.

When operating the motor with unbalanced primary, the secondary terminal voltage is the summation of the positive- and negative-sequence voltages being generated in the rotor coils. For normal operation with balanced primary voltage, only the positive sequence exists, and the secondary voltage has a perfectly finite magnitude and frequency for any selected speed (slip). Thus in the increasing speed range 0 to minus 100 per cent the magnitude increases from *Es* to 2*Es*, and the frequency increases from 60 to 120 cycles for 60-cycle applications. The appearance of the negative-sequence component, with its descending magnitude and frequency (60 to 0 cycles) in the same speed range, produces modulation in magnitude of the predominating positive-sequence component but does not affect

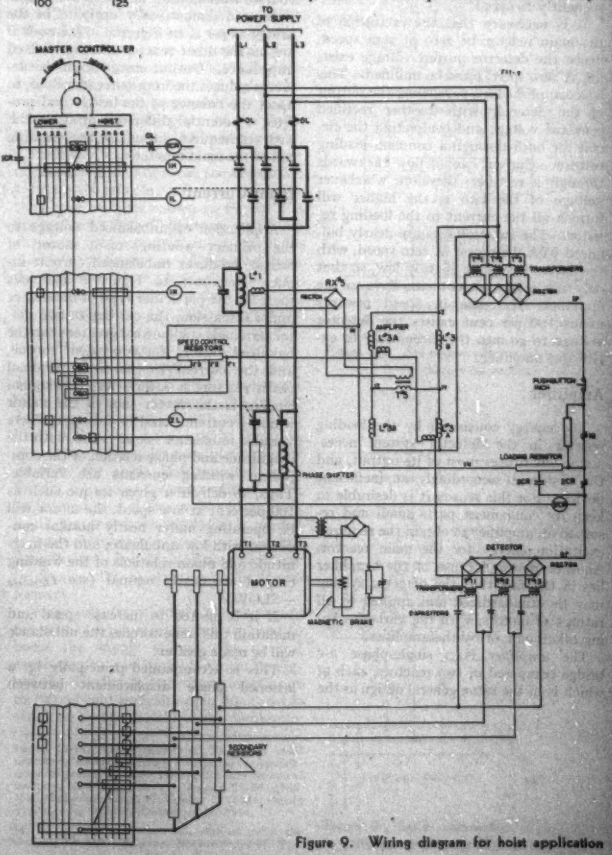

Figure 9. Wiring diagram for hoist application

with the applied frequency, therefore the terminal voltage on the transformer primary will increase as the frequency rises from 60 to 120 cycles. The wave form of the transformer secondary voltage is peaked rather than sine form due to the core saturation, and the increased primary voltage increases the amplitude of the peaks because of increased time rate of flux reversal. The increase in amplitude is accompanied by lessened duration, so that the energy per peak remains about constant. As the frequency rises there are more peaks per unit time, hence the output of the system varies directly as the frequency, except as modified by the relatively minor motor secondary voltage variations from other causes. The increase due to the presence of the capacitors can be made to transcend that due to other causes with the result that the output of the detector system responds fairly well to frequency and consequently to speed.

It is necessary that the excitation of the main reactor be zero at zero speed, hence the detector output voltage existing at zero speed must be nullified. This is accomplished by paralleling the output of the detector with another rectified constant voltage and completing the circuit for both through a common loading resistor. Current cannot flow backwards through a rectifier, therefore whichever voltage of the two is the higher will furnish all the current to the loading resistor. The two voltages are nearly balanced with the motor at zero speed, with the detector voltage slightly low, so that only negligible current can flow to the amplifier. Increase in speed towards minus 100 per cent causes the detector voltage to go into the ascendency to excite the amplifier.

Amplifier

The energy consumed by the loading resistor in the detector system necessarily constitutes most of its output, and the system is accordingly an inefficient device. For this reason it is desirable to keep its component parts small and resort to an amplifier to obtain the required excitation energy for the main reactor. Another reason for use of the amplifier lies in the fact that the detector system may be standardized and applied to all ratings of motors, with the variables being taken care of by the amplifier.

The *amplifier* is a single-phase a-c bridge composed of two reactors, each of which is of the same general design as the main reactor, except that the d-c exciting coil is omitted from one. The impedance of the reactor with the exciting coil is, of course, variable and its two a-c coils are connected diametrically opposite in the bridge as per *A* in Figure 6. The coils *B* are on the other reactor and are of fixed impedance. Output energy from the detector reduces the impedance of coils *A*, to upset the balance of the bridge and produce a potential difference at *X* and *Y* with consequent input to the exciting coil of the main reactor.

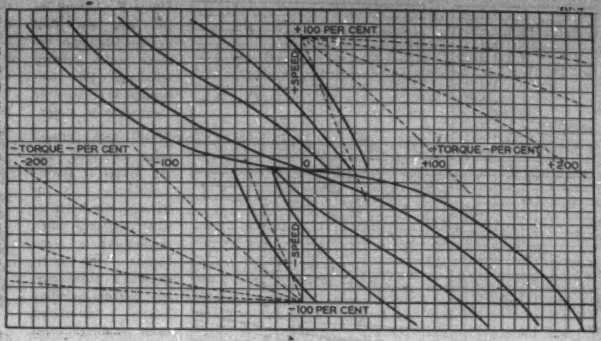

Figure 10

Dotted curves are characteristics for orthodox reversing controller; solid curves show some possibilities obtainable with variable unbalance

Input Current

Application of unbalanced voltage to the primary windings of a motor, of course, produces unbalanced current input. Reference to Figure 8 indicates that, for the particular type of unbalance under discussion, the current to two motor terminals is somewhat greater than the balanced current for equivalent torque, and the current to the third terminal (with reactor) is always less. Terminal current is the vector sum of the motor winding currents, and in this case where variable unbalance is concerned, both the magnitude and phase relation of the component winding currents are variable. Thus, to deliver a given torque such as 100 per cent at low speed, the motor will be operating under nearly normal conditions with low unbalance, and the magnitude and phase relations of the winding current are nearly normal (see $I_{L1,L2,L3}$—SLOW).

If it is desired to increase speed and maintain this same torque, the unbalance will be made greater.

This is accompanied principally by a lessened phase displacement between component winding currents, and some increase in magnitude. The terminal current changes to $I_{L1,L2,L3}$—FAST, as shown in Figure 8. The effect of such changed displacement angles for the current in the three windings of Figure 2 will be appreciated by study of the typical vector diagrams in Figure 7.

Conclusions

A wiring diagram for this control system, as it would be applied to a crane hoist, is shown in Figure 8. The above description has stressed fourth-quadrant performance and the test curves shown were taken with the average primary current limited to 125% at rated load. These conditions should not be regarded as limitations but rather as particular values for a particular application. It is self-evident that with the large number of control elements available many combinations of values may be used giving equivalent variations and modifications in performance.

A simple reversal of motor terminal connections produces performance in the first and second quadrants equal to that developed in the third and fourth. Figure 9 then shows how this new system has produced speed–torque curves filling in a much needed portion of the speed–torque area, supplying a valuable tool for the design engineer.

Design of Sealed Ignitron Rectifiers for Three-Wire Service

M. M. MORACK
MEMBER AIEE

IN the past four years, the many constructional and operational advantages of sealed ignitron rectifiers have greatly aided the war effort by saving critical materials and manufacturing facilities. Two-wire sealed ignitron rectifiers[1] have met industry's urgent need for efficient d-c power and have found wide application in the range of 75- to 1,000-kw capacity, at voltages ranging between 250 and 600 volts direct current for general industrial, railway, mining, and electrochemical service.

The field of application of the ignitron rectifier is considerably enlarged by the introduction of equipments for three-wire service, and it is the purpose of this paper to describe the design, characteristics, and performance of these units.

The Field for the Three-Wire Rectifier

One field of usefulness of the three-wire rectifier is for supplying d-c power to industrial three-wire systems. There is another application to be found in metropolitan districts where steps are being taken to retire the Edison three-wire d-c system and existing building generating plants. In many cases it will not be economical to rewire buildings for a 208-volt three-phase 60-cycle supply or to replace d-c motors and control for a-c operation. The problem of supplying d-c power for three-wire systems without the installation of rotating apparatus has long delayed the conversion in many districts.

Three-wire sealed ignitron rectifiers offer several distinct advantages when compared with other forms of converting equipment. The rectifier is largely static, thus eliminating special foundation and space requirements. Rectifiers are quiet in operation and easy to operate. The no-load losses are small and the efficiency is fairly constant and reasonably high over the entire load range. Rectifier equipments are factory assembled as unit d-c substations thereby minimizing installation time and expense.

Design and Operating Characteristics

Power Circuits

Three-wire service can be furnished by rectifiers in a number of ways: Large industrial three-wire requirements may be met by standard two-wire rectifiers operating at 250 volts in conjunction with a balancer set as shown in Figure 1. The alternating voltage of factory distribution systems will be above the 208-volt level so that rectifier transformers will be required. Noise levels and space requirements are not determining factors.

Another class of three-wire service is offered by dry-dock applications where 250/125-volt equipment is required for 100 per cent unbalanced operation or for double current capacity at 125 volts. Here the series or parallel operation of two 125-volt rectifiers is preferable. The efficiency of this power-circuit arrangement is about the same as rotating equipment, but it has the advantage of flexibility and ease of operation. For higher ratings, two delta six-phase double-wye power circuits are used in place of the delta three-phase single-way[2] units of Figure 2.

In larger cities, where programs are under way to limit or retire the Edison d-c system, the simple and less expensive three-wire rectifier shown in Figure 3 is applicable. Sealed ignitron rectifying elements are arranged in a six-phase double-way circuit[3] to take power from the 208-volt three-phase 60-cycle network. The neutral of the three-wire load is obtained from the 208-volt network grounded neutral so that the complication of the balancer set is eliminated.

Tests indicate that when a 75-kw double-way rectifier is supplied directly from the 208-volt network, the output voltage will vary from 247 volts at no load to 237 volts at full load as shown in Figure 4a. This voltage regulation is satisfactory for single elevators and small motors connected to one rectifier. For larger numbers of elevators and lighting loads, better voltage regulation is needed to prevent rough elevator operation and lamp flicker. Suitable voltage ratios may be obtained by the addition of autotransformers.

When autotransformers of five to ten per cent of equipment rating are used to boost the supply voltage, the natural regulation characteristic is shown in Figure 4b. The flat voltage characteristic out to 100 per cent load, shown in Figure 4c, is obtained by the use of voltage regulators. Regulated output characteristics may be had without the use of autotransformers when a line-to-neutral voltage below 125 volts is acceptable.

The double-way power circuit is capable of supplying 100 per cent current to a completely unbalanced load on the basis of rectifying element rating; however, such loads produce d-c components in the network transformer and thereby tend to increase exciting current. For partially balanced loads, the line-to-line component gives six-phase current wave shapes while the unbalanced portion is three-phase single-way. Figure 5 shows the network high-voltage current wave shape for balanced and for 50 per cent unbalanced load conditions for a rectifier.

Tests made on a 75-kw three-wire recti-

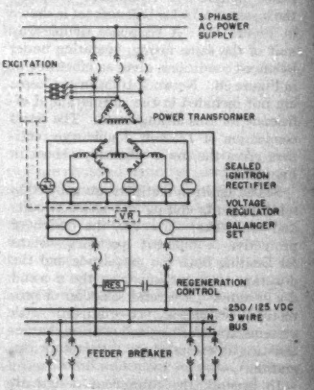

Figure 1. Six-phase double-wye rectifier for three-wire service

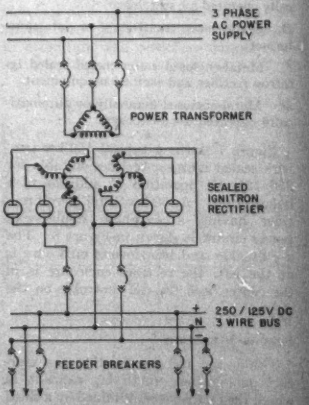

Figure 2. Series connection of three-phase zigzag rectifiers for three-wire service

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fier operating on a 600-kva delta–wye transformer bank indicate that the difference in temperature rise for the two load conditions is due chiefly to the increase in core loss. The difference in temperature rise for two eight-hour heat runs made with balanced and fully unbalanced load was about three degrees centigrade.

In large network transformers, the d-c component would have less effect on the core loss than shown in the test run since the relative size of transformers would be greater. Also, the unbalanced condition created for test is greater than would be encountered in practice where the rectifier would seldom be called upon to furnish more than 25 per cent unbalance.

Relative efficiencies for the foregoing power-circuit arrangements are shown in Figure 6. The efficiency of a 150-kw six-phase double-wye equipment including the losses of a 15-kw balancer set is shown in Figure 6a. A six-phase double-way unit of the same rating, operating under balanced conditions, gives an efficiency as in Figure 6b. Network-transformer losses are not included in the calculation of efficiency for this arrangement. The series connection of 125-volt double-wye rectifiers gives the lower efficiency shown in Figure 6c.

Sealed ignitron rectifiers are subject to fault currents during d-c short circuits and arc-backs; however, the design of protective equipment provides means for limiting both the magnitude and the duration of disturbances on the a-c and d-c systems. A careful selection of protective switchgear, co-ordinated with systems, transformer, and rectifier characteristics, is essential for satisfactory operation.

In general, the equipment design allows factory-assembled unit substations consisting of the following components:

A. Metal-enclosed manually or automatically operated a-c switchgear.

B. Main power transformer or autotransformer.

C. Metal-enclosed water-cooled sealed ignitron rectifier and excitation equipment.

D. Metal-enclosed manually or automatically operated d-c switchgear.

Figure 7 shows a typical 150-kw two-wire sealed ignitron rectifier suitable for 250/125-volt operation by addition of a balancer set. A 150-kw 250/125-volt rectifier having a six-phase double-way power circuit is shown in Figure 8. The a-c breaker and transformer enclosure is at the left, the rectifier enclosure is in the center, and the d-c control is on the right.

Sealed Ignitrons

The design and construction of a mercury-pool-cathode rectifying element in which the control is maintained by a third electrode, or ignitor, is shown in Figure 9. Elements of the ignitron are a seamless steel water-jacketed resistance-welded vacuum chamber containing a main graphite anode, an auxiliary anode, two ignitor tips, deionization baffles, and a mercury-pool cathode.

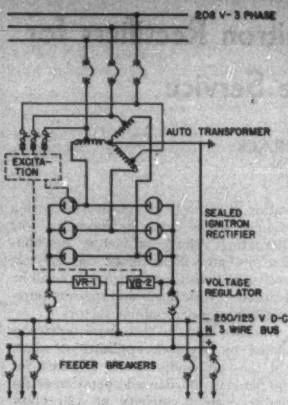


Figure 3. Six-phase double-way three-wire rectifier

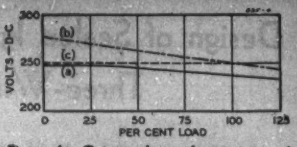


Figure 4. Output-voltage characteristics of six-phase double-way rectifier

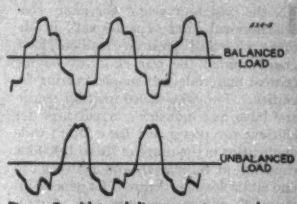


Figure 5. Network-line-current wave shapes with rectifier load

Ignitor tips are made of boron carbide, a refractory material having high specific resistance. The function of the ignitor is to control the time at which the anode current begins to flow. Once the ignitor has initiated the discharge, it has no further effect on the anode current. Control is restored to the ignitor when the main-anode and auxiliary-anode currents cease long enough for the mercury to become sufficiently deionized.

The flexible stranded anode lead, with its pressed-copper terminal, is silver-soldered to a steel stud which supports the graphite anode. This entire assembly is insulated from the cylinder, which is at cathode potential, by means of a glass-to-metal-alloy seal. These last materials have practically the same coefficient of expansion over a wide temperature range, and their use results in vacuum-tight operation.

After the cathode spot has been created by the ignitor, the auxiliary anode functions to maintain the spot for the remainder of the main anode period. This provides sufficient ionization to enable the main anode to carry the load current, even at small percentages of rating.

Uniform cooling of all parts of the vacuum chamber is accomplished with water. Water flow is directed upward by helical vanes to avoid air pockets or hot spots.

Magnetic Excitation Equipment

Each anode of an ignitron rectifier is associated with an ignitor which requires a positive impulse current once each cycle to start the arc. In order to fire the ignitors at the correct predetermined time, the magnetic-excitation circuit[4] shown in Figure 10 is used extensively for two-wire rectifiers. The phase position of the ignitor impulses can be adjusted by controlling the saturation in the phase-shifting reactor *PL*. A direct current of 1.5 amperes furnished by a regulator may be used to vary the firing point of the ignitor over an angle of approximately 50 degrees as shown in Figure 11.

For double-way three-wire rectifiers, ignitors which are 180 degrees apart in phase relation operate at different cathode potentials and an insulating transformer is used in the circuit. In addition, a phase shift between 180-degree ignitors is required for line-to-neutral regulation. The excitation circuit is arranged as in Figure 12.

The operation of the circuit is similar to that of Figure 10 except that a presaturating winding is provided on the nonlinear reactor *FL* for shifting the 180-degree ignitor peaks with respect to each other. When a direct saturating current is applied in one direction, the positive peak advances and the negative peak retards. When the saturating current is reversed the peaks shift the opposite way. In this manner a ten-degree dissymmetry can be used for the line-to-neutral voltage regulation.

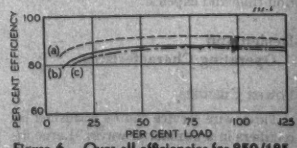


Figure 6. Over-all efficiencies for 250/125-volt 150-kw ignitron rectifiers

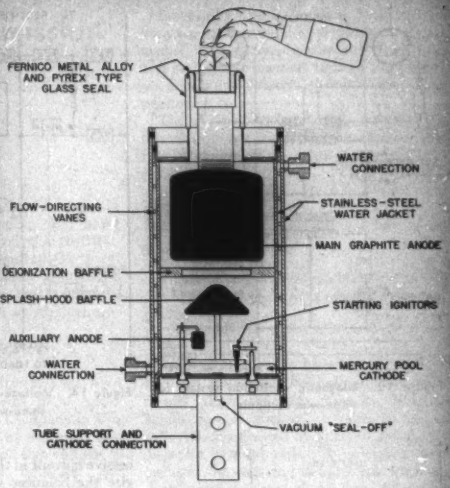


Figure 7 (above). Metal-enclosed sealed ignitron rectifier rated 150 kw, 250 volts direct current

Figure 9 (right). Section of a sealed ignitron

Voltage-Regulating Equipment

Rectifiers in common with other electric apparatus have regulation. To mitigate the drop in direct voltage, and to compensate for variations in the rectifier supply voltage, the phase position of the ignitor voltage is varied with respect to the positive half-cycle of anode voltage by a direct voltage regulator as shown in Figure 13.

The regulator consists of a rheostatic element, and a magnetic voltage-sensitive element connected by a spring-balanced mechanical link. In the regulator circuit, the rheostatic element forms one arm of a resistance bridge connected across the output of the rectifier. The saturating-current windings of the phase-shifting reactors *PL* in the excitation circuit of Figure 10 are connected between the midpoints of the bridge. When the d-c output rises, the carbon stacks forming the rheostatic element are tilted, and their resistance increases. This change of resistance in one arm of the bridge results in decreased current flow in the saturating windings of the phase-shifting reactors, thus phase retarding the ignitors, and

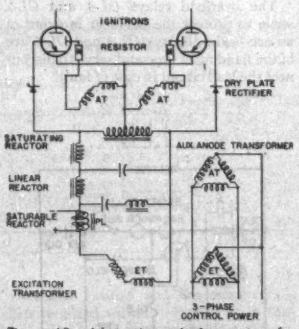


Figure 10. Magnetic excitation system for two-wire rectifiers

Figure 8. Metal-enclosed sealed ignitron rectifier rated 150 kw, 250/125 volts direct current

decreasing the direct voltage. The rheostat is provided for adjustment of the voltage to be held. The regulator will maintain the selected voltage from no load to full load within plus or minus one per cent, within the range of 15 per cent voltage control imposed by the limitations of the excitation circuit. For parallel operation of two or more rectifiers, an equalizer connection is made by joining the equalizing coils in series across the opposing voltage drops of the cathode shunts of the two machines.

The voltage-regulating equipment for the six-phase double-way three-wire rectifier uses two regulators, one to maintain line-to-line voltage, and the other to regulate the line-to-neutral voltage at one-half the line-to-line value. From Figure 14 it will be noted that the line-to-line regulator is similar to the bridge regulator of the two-wire rectifier in that all ignitors are phase advanced or retarded in response to variations in the output voltage.

To accomplish line-to-neutral voltage regulation, additional means are provided for phase shifting the ignition points of rectifying elements 180 degrees apart in phase relationship. The line-to-neutral regulator has a main coil connected in series with the voltage-adjusting rheostat across the line-to-neutral voltage. The rheostatic elements, fixed resistors, and firing reactor saturating windings *PL* form a bridge connected across line-to-neutral voltage. Two rheostatic elements are normally open and two are normally closed, so that movement of the linkage in one direction increases current in one element and decreases current in the other, thus allowing current to change in magnitude and direction through the

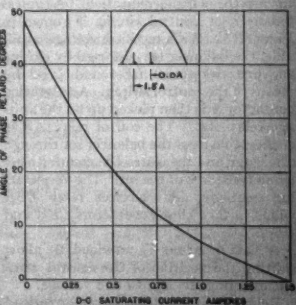


Figure 11. Phase-shift characteristics of magnetic excitation circuit

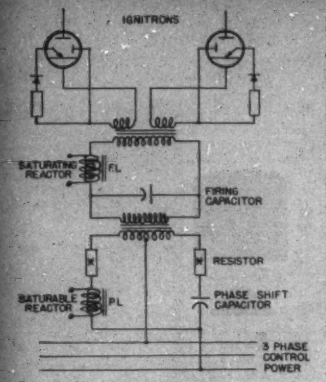


Figure 12. Magnetic excitation system for three-wire rectifiers

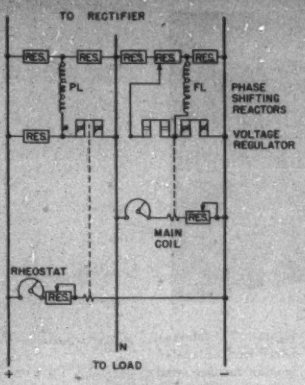


Figure 14. Voltage-regulating equipment for three-wire rectifier

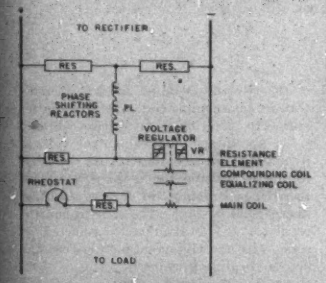


Figure 13. Voltage-regulating equipment for two-wire rectifier

saturating windings in accordance with the line-to-neutral voltage.

Balancer Set

Three-wire service is provided from two-wire rectifiers by a balancer set connected across the 250-volt d-c output to furnish the neutral connection. A typical balancer-set control circuit is shown in Figure 15. With rectified voltage available, the balancer set is started by closing the line contactors *LE*-1 and *LE*-2 by means of the control switch. Accelerating contactor *A* is then picked up by the voltage relay *AR*. The coil of relay *AR* is connected across the balancer set through a resistor and measures the counter electromotive force of the set. The accelerating contactor *A* energizes relay *CBR* which in turn closes contactors *CB*-1 and *CB*-2.

A field rheostat is provided to allow shifting the position of the neutral without affecting the line-to-line voltage.

Relay *OL*-3 is of the thermal-overload type and serves to protect the balancer set against excessive unbalanced load. Excessive current in the neutral will de-energize the balancer set and disconnect all load from the rectifier.

The overload relays *OL*-1 and *OL*-2 serve to protect the balancer in event of an arc-back. Relays *OL*-4 and *OL*-5 are of the hand reset type and serve to disconnect the load circuit in case of fault.

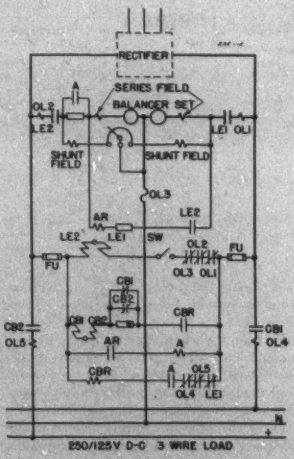


Figure 15. Balancer-set circuit for two-wire rectifiers

A—Accelerating contactor
AR—Accelerating relay
CB—Circuit-breaker contactor
CBR—Auxiliary relay
OL—Overload relay
•—Resistor
SW—Switch
FU—Fuse

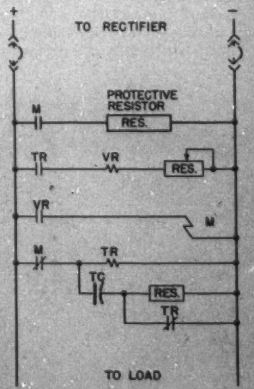
The rating of the balancer set is determined by the requirements of the application. A balancer set of 25 per cent of the rectifier rating is sufficient for most applications.

Regenerative-Braking Protective Equipment

A rectifier operating under normal conditions will not carry reverse current, and any load which tends to regenerate will cause the d-c bus voltage to rise. Protection must be provided by a "pump-back" resistor, connected across the bus by a contactor whenever reverse power is encountered, and removed when the regeneration ceases. The resistor is usually designed to absorb about ten per cent of the rectifier rating and is sufficient for cranes, elevators, and other similar loads where regeneration occurs at infrequent intervals.

The operation of the protective equipment may be understood by reference to Figure 16. Whenever regeneration is present the bus voltage will rise rapidly provided there is no other load which can absorb the regenerative power. A fast-acting relay *VR* is adjusted to operate at a voltage slightly higher than the normal rectifier rating. The coil of *VR* is energized through the timing-relay contacts *TR*. The coil circuit *TR* is completed through the normally closed interlock on the main contactor *M*.

The operation of *VR* closes *M*, connecting the protective resistor across the line. The bus voltage is maintained by the rectifier and *VR* remains closed until the contacts *TR* open after a time delay obtained by the long time constant of the circuit and a copper-jacketed coil. If re-



[Figure 16. Regeneration-control circuit

M—Main contactor
VR—Voltage relay
TR—Time relay
TC—Timing capacitor

Lightning Investigation on Transmission Lines—VIII

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FELLOW AIEE

C. M. FOUST
MEMBER AIEE

PREVIOUS papers of this series gave data on a lightning investigation carried on co-operatively by a number of power companies and the General Electric Company, and the seventh paper of the series[1] brought the data up to and including 1938. Additional papers[2,3] covered special angles of the investigation.

The present paper discusses an investigation, under the joint sponsorship of the American Gas and Electric Service Corporation, of voltages, currents, and rates of change of voltage at five stations of the Appalachian Electric Power Company in Virginia; data on currents in towers and strokes on the lines of five different power companies; and some additional information on the distribution of current in counterpoise wires and driven rods, and voltage gradient in the vicinity of towers on the Consumers Power Company system in Michigan.

Paper 45-26, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted October 30, 1944; made available for printing December 11, 1944.

W. W. LEWIS is with the central-station engineering divisions and C. M. FOUST with the general engineering laboratory, both with General Electric Company, Schenectady, N. Y.

The authors acknowledge the co-operation in this investigation of I. W. Gross and G. D. Lippert of the American Gas and Electric Service Corporation; J. G. Hemstreet and C. C. Tanner of the Consumers Power Company; L. M. Robertson of the Public Service Company of Colorado; and R. P. McAtee and J. G. Hutton of the general engineering laboratory and D. D. MacCarthy and W. N. Neiman of the lightning-arrester engineering division of General Electric Company.

The Wave-Slope Indicator

The wave-slope indicator first was used in 1939 on the 132-kv lines of the Appalachian Electric Power Company in Virginia.[4] The object was to obtain an idea of the rate of change of the voltage of transient waves from lightning and switching traveling into the stations.

Table I. Wave-Slope-Indicator Link Arrangement and Ratio

Link No.	Turns in Coil	Ratio
1	35	610
2	10	246
3	8.5	98
4	1.5	39
5	Adjacent to 10-turn coil	15.6
6	Adjacent to 10-turn coil	6.25
7	Adjacent to 10-turn coil	2.5
8	Adjacent to 10-turn coil	1.0

Essentially the instrument is a combination of a coupling capacitor, connected between conductors and ground, and surge-crest magnets to read the crest or maximum current through the capacitor.

The crest of the capacitor current is directly proportional to the maximum rate of change of capacitor voltage, that is,

$$I = C\frac{de}{dt}$$

in which

I = crest of current through capacitor
C = capacitance of coupling capacitor
$\frac{de}{dt}$ = maximum rate of change of voltage

A measuring range from 10 to 10,000 amperes crest capacitor current was obtained through eight magnetic links. Links were located in air cores of low-inductance coils and at selected spacings adjacent to these coils. By selecting the turns in the coils and the link spacings, a magnetization ratio of 2.5 was obtained between adjacent links, thus giving a ratio between links 1 and 8 of about 610. These ratios were verified by laboratory tests with the cathode-ray oscillograph, in which current surges of known magnitude and wave shape were used.

Links were installed in the cores of 35-, 10-, 3.5-, and 1.5-turn coils; also four additional links were placed adjacent to the 10-turn coil. The numbering of the links and the approximate ratios were as shown in Table I.

The original arrangement was continued during the years 1939, 1940, and

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generation still persists when *TR* opens, the circuit will recycle.

Application

The design of sealed-ignitron-rectifier equipment for three-wire operation is determined to a large extent by the nature of the application. The six-phase double-wye power circuits offer the best efficiency and output wave form but require the added complications and losses of a balancer set. Series connection of 125-volt rectifiers eliminates the balancer equipment, provides flexibility, and is suitable for 100 per cent current unbalance, but gives six per cent lower efficiency and higher no-load losses.

The six-phase double-way power circuit offers the best solution to the change-over problem. Such equipment is economical to build and requires a minimum of space which is usually hard to find in existing buildings. The rectifier provides a medium efficiency of 86 per cent. Satisfactory voltage regulation can be provided by autotransformers and voltage regulators.

Rectifier ratings and the number of units required will also depend upon the application. For elevator loads, particularly in hotels, apartment houses, and office buildings it is good practice to have a 100 per cent reserve or stand-by unit, which will permit the rectifier in service to be removed. For reasons of safety, such service must continue under all conditions and a satisfactory solution to the problem is to provide two complete independent rectifiers with provisions for rapid change-over in case of direct-voltage failure. Simple switching provides preselection of normally operating and reserve rectifiers. Where requirements are less severe and where units may be removed for maintenance and inspection, it is not necessary to provide a stand-by unit.

Conclusions

The basic problems of sealed ignitron rectifiers for three-wire service have been solved and the equipments are highly reliable when properly applied, installed, and serviced. The type of power circuit is dependent on the requirements of the application. Tests show that the additional heating in network transformers resulting from the unbalanced load on the six-phase double-way circuit will be negligible and that the circuit offers an efficient, economical, three-wire rectifier where 208-volt power is available. The equipment is semiautomatic in operation, so that periodic inspection and cleaning is all that is necessary to insure continuous and reliable operation.

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1. SEALED-TUBE IGNITRON RECTIFIERS, M. M. Morack, H. C. Steiner. AIEE TRANSACTIONS, volume 61, 1942, August section, pages 594–9.

2. RECTIFIER TERMINOLOGY AND CIRCUIT ANALYSIS, C. H. Willis, C. C. Herskind. AIEE TRANSACTIONS, volume 61, 1942, July section, pages 496–9.

3. THREE-PHASE RECTIFIER CIRCUITS, A. J. Maslin. *Electronics*, volume 9, December 1936, page 28.

4. IGNITOR EXCITATION CIRCUITS AND MISFIRE INDICATION CIRCUITS, A. H. Mittag, A. Schmidt, Jr. AIEE TRANSACTIONS, volume 61, 1942, August section, pages 574–7.

Table II. Wave-Slope-Indicator Calibration

Undamped-Surge Oscillatory Calibration

1 Surge-Generator Excitation, Volts	2 Link Position	3 SCA Scale Reading Group 1	4 SCA Scale Reading Group 2	5 SCA Scale Reading Group 3	6 SCA Scale Reading Average	7 Ratio	8 Per Cent Oscillation	9 Capacitor Current	10 Wave Slopes Link Kv Per μsec	11 Wave Slopes Link Average	12 CRO Kv Per μsec	13 Deviation, Per Cent
	2	R10	R5	R16	10.3							
32	3	R53	R46	R41	46.7	1.30	15	400	240	222	228	−2.6
	4	R36	R36	R36	36.0	2.37	15	344	205			
	5	R16	R15	R14.5	15.2							
	2	D28	D23	D18	23.0							
	3	R46	R38	R33.5	39.2	0.92	15	487	290	272	270	+0.7
38	4	R46	R41.5	R41	42.8	2.34	14	430	255			
	5	R20	R19	R15	19.0	2.04						
	6	R10	R8	R10	9.3							
	2	D33	D30	D26	29.7							
	3	R41	R33	R26	33.3	0.72	13	624	380	340	312	+9.0
44	4	R51	R44	R44	46.3	2.07	15	500	300			
	5	R23.5	R21.5	R22	22.5	2.06						
	6	R10.5	R10	R12	10.8							
	7	0	Rtr	Rtr								
	2	D38	D41	D34	37.7							
	3	R36	R28	R34	29.5	0.63	15	624	380	355	355	0
50	4	R53	R44	R45	47.3	1.95	15	550	330			
	5	R26	R22	R24.5	24.2	2.02						
	6	R12	R11	R13	12.0	3.00						
	7	Rtr	R5	R5	4.0							
	2	D49	D38	D30	35.0							
	3	R31	R34	R19	28.0	0.60	15	610	375	378	398	−5
56	4	R54	R44	R42	46.7	1.75	16	630	380			
	5	R26.5	R26	R26	26.8	3.14						
	6	R13	R11.5	R14	12.8	3.10						
	7	Rtr	Rtr	R5	4.0							
	2	D50	D41	D52	47.7							
	3	R22.5	D10	R11	14.5	0.31	15	630	390	435	440	−3.4
62	4	R52	R42	R46	46.7	1.47	16	750	460			
	5	R34	R30	R31	31.7	2.07						
	6	R14	R16	R16	15.3	2.19						
	7	R5	R8	R8	7.0							

D=direct reading on surge-crest ammeter (*SCA*) *R*=reverse reading on surge-crest ammeter *CRO*=cathode-ray oscillograph *tr*=trace

1941, modified somewhat in 1942, and again in 1943. The 35-turn coil and link 1 of the original installation were omitted. The final connections were as shown in Figure 1.

Carrier-current coupling capacitors of 0.00025, 0.0005, 0.001, and 0.0015 microfarad which were on the system were utilized. A total of 26 instruments was located on ten circuits at Glenlyn, Claytor, Roanoke, Reusens, and Fieldale.

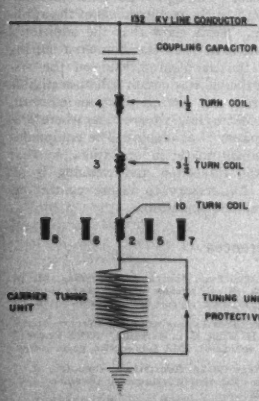

Figure 1. Final wave-slope-indicator arrangement of 1943

Numbered capsules represent magnetic links

A typical calibration curve of one of the coils is shown in Figure 2, and Figure 3 shows the relation between maximum-voltage wave slope and crest capacitor current for each value of capacitor used. A range of voltage steepness of from 10 to 10,000 kv per microsecond was covered by the arrangement.

Specimen Laboratory Calibration

The arrangement of coupling capacitor, coils, and magnetic links, as used on the transmission line and shown in Figure 1, was calibrated in the laboratory with surge-generator discharges of differing voltage wave shapes. These wave shapes were of three general types as to polarity—unidirectional, oscillatory, and repeated unidirectional of mixed polarities. Representative of these calibrations is one which included the application of both damped and undamped oscillations and provided a direct comparison of numerical values of voltage wave slopes recorded by cathode-ray oscillograph with those indicated by the magnetic links.

For both the damped and undamped circuits the wave slope was varied over a considerable range by varying the surge-generator excitation voltage. Magnetic links occupied all link positions from 2 to 8 as shown on Figure 1, and three groups of links were used for checking purposes. Tables II and III summarize data collected for these calibrations and show the several steps involved in interpretation of wave-slope values. As both the damped and undamped waves were oscillatory, a two-link oscillatory calibration was used, such as shown in Figure 5 of reference 5.

In Tables II and III, column 1 gives the surge-generator excitation voltage, which was increased progressively to provide for some range of wave slopes. Column 2 is the reference number for individual link positions as indicated in

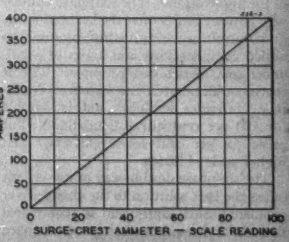

Figure 2. Typical calibration curve for one of the wave-slope-indicator coils

Calibration of 3.5-turn coil, link 3, ammeter reading versus amperes

Table III. Wave-Slope-Indicator Calibration

Damped-Surge Oscillatory Calibration

1 Surge-Generator Excitation, Volts	2 Link Position	3 SCA Scale Reading Group 1	4 SCA Scale Reading Group 2	5 SCA Scale Reading Group 3	Average	7 Ratio	8 Per Cent Oscillation	9 Capacitor Current	10 Wave Slopes Link Kv Per μsec	11 Wave Slopes Link Average	12 CRO Kv Per μsec	13 Deviation Per Cent
32	2	R100+	R100+	R90	97+	1.33						
	3	R80	R69	R70	73	2.28	6	300	180			
	4	R32	R34	R30	32	2.41	14	344	207	193	188	−2.5
	5	R14	R13.5	R13	13.5	3.50						
	6	Rtr	R5	Rtr	4							
38	2	R100+	R83	R80	88	1.12						
	3	R88	R76	R73	79.0	1.84	6	436	265			
	4	R44	R44	R43	43.7	2.71	0	368	225	245	232	+5.6
	5	R17	R15	R16	16.0	2.00						
	6	R5	R10	R10	8.0							
44	3	R100	R79	R75	84.7	1.65	5	530	320			
	4	R52	R52	R50	51.3	2.90	0	432	260	290	270	+7.4
	5	R49	R17	R17	17.7	1.77						
	6	R10	R10	R10	10.0							
50	3	R100+	R78	R74	84	1.44	6	610	370			
	4	R64	R58	R56	59.3	2.96	0	500	300	335	308	+9.0
	5	R22	R19	R19	20.0	1.97						
	6	R10	R10	R11	10.3							
	7	0	Rtr	Rtr								
56	4	R72	R67	R61	66.6	2.86	0	559	340	340	345	−1.5
	5	R25.5	R25.5	R22	23.3	2.09						
	6	R10.5	R11	R12	11.2							
	7	0	Rtr	R5								
62	4	R78	R68	R68	71.3	2.55	0	605	370	370	382	−3.1
	5	R39	R34.5	R30	37.8	2.39						
	6	R12	R12	R12	12.0							
	7	0	Rtr	R5								

D = direct reading on surge-crest ammeter (*SCA*) *R* = reverse reading on surge-crest ammeter *CRO* = Cathode-ray oscillograph *tr* = trace

Figure 1. Columns 3, 4, and 5 are three groups of magnetic-link records, each obtained by the application of a single surge of the same wave shape as obtained at each excitation voltage of column 1. These three groups of links were used to check link variations on the same surge. In column 6 are given the average values for each link position for the three groups of links. In the measurement setup magnetization of links 2, 3, and 4 is normally opposite from that of links 5, 6, 7, and 8. For convenience in analysis, however, records from links 5, 6, and 7 have been put down in these tables in reverse to their actual polarity.

In the interpretation of wave slopes the oscillatory-calibration method requires the calculation of an inner-link–outer-link ratio as given in column 7. This ratio is the same as that for a normal surge-crest-ammeter two-magnetic-link station, as used extensively for tower leg, line conductor, and down-leads in previously reported field lightning investigations. In this wave-slope method the inner link is the link operating in the next stronger magnetic-field position to any other link. For instance, link 2 of Figure 1 in the 10-turn coil is inner link to link 3 in the $3^1/_2$-turn coil. Relative field intensities between link positions is 2.5 to 1. In the tables the inner–outer-link ratio is entered on the corresponding inner-link line. If we refer now to the appropriate oscillatory-calibration curve, the per cent oscillation and capacitor currents of column 8 and 9 are read directly. This is done similarly for each inner-link–outer-link combination of adjacent links. The current values of column 9 are translated to wave-slope values, column 10, by use of a curve such as shown in Figure 3. When more than one value of wave slope for a single surge application can be derived from the magnetic links, the values should check and be averaged for the final wave-slope value. Such averages are given in column 11, and in column 12 are recorded wave-slope values derived from cathode-ray oscillograms. A percentage comparison of magnetic-link values and cathode-ray oscillograph values is given in column 13.

Table IV. Wave-Slope-Indicator Records—Analysis by Link Position, 1939 to 1943, Inclusive

Appalachian Electric Power Company 132-Kv System

Range, Kv Per Microsecond	Links 2–3	Links 3–4	Links 4–5 and 5–6	Total No.	No. at or Above Level	Percentage at or Above Level
11–20	7	0	0	7	589	100.0
21–30	9	0	0	9	582	98.8
31–40	51	0	0	51	573	97.2
41–50	45	2	0	47	522	88.6
51–60	54	1	0	55	475	80.6
61–80	43	20	0	63	420	71.4
81–100	19	43	1	63	357	60.6
101–150	33	104	3	140	294	49.9
151–200	11	44	12	67	154	26.15
201–250	19	11	3	33	87	14.77
251–300	8	19	5	32	54	9.17
301–350		12	2	14	22	3.74
351–400		2	0	2	8	1.36
401–450		2	0	2	6	1.02
451–500		1	0	1	4	0.68
520		1	0	1	3	0.51
524		1	0	1	2	0.34
550			1	1	1	0.17
Total	299	263	27	589		

The deviations for these tests range up to nine per cent which is the measurement accuracy of the magnetic links as commonly used for crest surge currents. In deriving wave-slope values from the magnetic links, some measure of experience in weighting of values from different link positions is required. In general, surge-crest ammeter readings below 10 and above 90 on the instrument scale were rejected as possibly affected by small residuals and saturation levels.

The basic calibration curves on which all the field interpretations are made were

Table V. Surge Voltages on Station Busses, 1940–1943, Inclusive

Appalachian Electric Power Company 132-Kv System

Range of Voltage, Kv	1940*	1941*	1942†	1943**	Total	No. at or Above Level	Percentage at or Above Level
0–100			7	55	62	429	100.00
101–150	58	120	1	179	367	85.6
151–200	17	50	2	69	188	43.8
201–250	5	12	33	3	53	119	27.7
251–300	4	19	6	6	35	66	15.4
301–350	2	3	0	1	6	31	7.23
351–400	4	3	2	5	14	25	5.83
401–450	0	4	3	1	8	11	2.56
451–500	1			1	2	3	0.70
525	1				1	1	0.23
Total	17	116	221	75	429		
Maximum	525	428	420	473			

* Roanoke and Claytor stations.

† Roanoke, Claytor, and Fieldale stations.

** Roanoke station only.

Table VI. Insulation Flashover Strength of Lines and Stations Under Investigation on 132-Kv System of Appalachian Electric Power Company

Number of lines	6
Number of circuits	10
Number of overhead ground wires	1 per line
Number of stations	5
Number of connected lines at stations	2 to 5
Number of insulator units in line suspension strings (spaced 4¾, 5, and 5¼ inches)	10 to 12
Flashover of line-insulator strings (1.5x40 positive wave)	790 to 1,080 kv
Number of circuits equipped with protector tubes	4
Discharge voltage of protector tubes	
1.5x40 positive wave	680 kv
1.5x40 negative wave	760 kv
Number of insulator units in reduced line insulation (spaced 4¾, 5, and 5¼ inches), 5 towers adjacent to station (on all except tube-equipped lines)	9
Flashover of reduced line insulation (1.5x40 positive wave)	720 to 890 kv
Bus-insulation flashover strength	
1.5x40 positive wave	590 kv
1.5x40 negative wave	770 kv
Number of three-phase lightning arresters	16
Rating of arresters, 60-cycle rms	106, 109, 121 kv
Arrester-gap breakdown (1.5x40 voltage wave) or IR drop at 5,000 amperes (10x20 current wave)	350 to 425 kv

Table VIA. Comparison of Insulator Units Spaced 5¾ Inches Apart

No. of Insulator Disks	Flashover Kv 1.5x40 Positive Wave	Flashover Kv 1.5x40 Negative Wave
8	780	760
9	860	845
10	945	930
11	1,025	1,015
12	1,105	1,105

built up similar to the calibration checks of Tables II and III, requiring, of course, the use of generated wave shapes including a wide range of damping factors.

Wave-Slope-Indicator Records

The analysis of the wave-slope-indicator records was made by two methods. The first method of analysis consisted of classifying the records according to the ratio of adjacent-link readings and using an appropriate set of calibration curves. The purpose of this method was to determine the rates of voltage change from surges due to all causes.

The second method of analysis consisted of grouping the records according to link position. The purpose of this method was to determine the origin of the surges; that is, whether due to lightning, switching, or a combination of both.

Analysis by First Method

The classification by the first method is as follows:

Class 1—Unidirectional surges only.

Class 2*A*—Oscillatory surges from three-link readings.

Class 2*B*—Oscillatory surges from two-link readings.

Class 3—Superimposed repeated surges. Rate of voltage change doubtful.

Class 4—Single-link readings. Surge characteristics uncertain; calibrated as unidirectional.

Class 5—Adjacent link polarities reversed. Surge characteristics uncertain.

During the years 1929 to 1943, inclusive, there were 979 records in all, with one class-5 record of 810 kv per microsecond in the year 1942.

Analysis by Second Method

The records in classes 3, 4, and 5, comprising about 40 per cent of all the records, are somewhat uncertain, and there is some doubt as to their correct interpretation. These records, therefore, have been rejected in making the analysis by the second method. In this analysis of the wave-slope records it was found by specially staged tests made in 1939, that the links nearest the current-carrying coils of the wave-slope indicator are always affected by switching surges. As the distance between the links and the coils increased, the effect diminished rapidly, and links 5 and 6 did not appear to be affected appreciably by switching surges. Records from links 2 and 3 therefore were considered to be due principally to switching; records from links 3 and 4 were considered to be due to switching or lightning or a combination of both; records from links 4 and 5 or 5 and 6 were considered to be due to lightning only.

A summary of the 589 records, according to the second method of analysis, for the five years, 1939 to 1943, inclusive, is given in Table IV.

In Figure 4 are plotted as abscissas the percentage of records at least equal to the kilovolts per microsecond as ordinates. The kilovolts per microsecond are given in zones, and in each case the bottom figure of the zone is plotted as ordinate, except for the three highest figures of 520, 524, and 550, which are plotted individually. Abscissas are plotted logarithmically. By this method of plotting a logarithmic curve will appear as a straight line, which permits ready extrapolations.

The sensitivity of the method does not lend itself to readings under about ten kilovolts per microsecond. Probably there are a large number of surges below this value which are not recorded. If these had been recorded, the percentage value for all other ranges would be reduced somewhat and the whole curve lowered.

Based on the data plotted, it would appear that surges were recorded about in the following order:

One in 2 (50 per cent)—at least 100 kv per microsecond.

One in 10 (10 per cent)—at least 225 kv per microsecond.

One in 100 (1 per cent)—at least 415 kv per microsecond.

One in 1,000 ($^1/_{10}$ per cent)—at least 605 kv per microsecond.

One in 10,000 ($^1/_{100}$ per cent)—at least 795 kv per microsecond.

Surge Voltages at Stations

Surge voltages were measured at Roanoke and Claytor stations of the Appalachian Electric Power Company in 1940; at Roanoke, Claytor, and Fieldale in 1941 and 1942; and at Roanoke only in 1943. The surge-voltage recorder with insulator string potentiometer was used. One instrument is used per phase and gives direct and reverse readings for each surge.[6]

As shown in Table V, 429 surges were recorded. The highest voltage recorded was 525 kv, and 50 per cent of all the surges were at least 145 kv.

Table VI gives the flashover strength

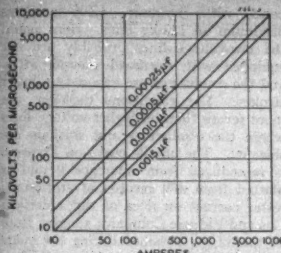

Figure 3. Relation between amperes and wave slope for various coupling capacitors

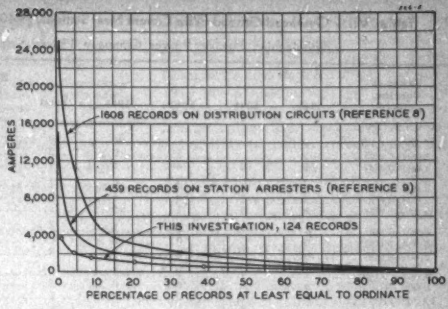

Figure 5 (right). Station-arrester currents at 132-kv stations of the Appalachian Electric Power Company, 124 records, 1940 to 1943, inclusive, and for comparison 1,608 records from distribution circuits,[7] and 459 records of station arresters 11 to 132 kv[9]

of the transmission-line and station insulation for the lines and stations at which instruments were located. The line insulation varies both in number and spacing of disks, so that the flashover ranges between 790 and 1,080 kv for the 1.5x40 positive wave. The negative-wave flashover with the 1.5x40 wave is not appreciably different from the positive, as will be seen from the comparison of insulator units spaced 5¾ inches apart,[7] given in Table VI.4.

All lines, exept those equipped with expulsion protector tubes, have reduced insulation for five towers (approximately one mile) out from the station. Nine disks of various spacings are used in this section, both in suspension and strain, with a flashover ranging from 720 to 850 kv. On the tube-equipped lines the incoming voltage is held to 680 kv with the 1.5x40 positive wave and 760 kv with the negative wave. The bus insulators will flash over at 590 kv with the 1.5x40 positive wave and 770 kv with the negative wave. Three types and ratings of station arresters are used, and it is estimated that with the 1.5x40 voltage wave or the 10x20 current wave, the arresters will hold voltages ranging from 350 to 425 kv.

With the line arrangement, that is, one or two circuits vertically arranged and one overhead ground wire, it is not likely that very many strokes will make direct contact with the conductors, but in most cases the voltage will get onto the conductor by insulator flashover or expulsion-protector-tube operation. The voltage reaching the station will therefore be limited to the reduced line-insulation flashover or tube-discharge voltage of the order of 680 to 850 kv. The waves will have some chance to attenuate in traveling to the station and then will be limited by the bus insulation to 590 to 770 kv and further by the arresters to 350 to 425 kv.

All of the measured voltages are well within the reduced line insulation, or expulsion-protector-tube, or bus-insulator flashover, and all but about six per cent are under the voltage assigned to the arresters.

In this investigation when a surge enters a station from a line it has anywhere from one to four other outgoing lines on which to dissipate itself, and also from one to four power transformer banks and from two to five banks of lightning arresters. If a surge impedance of 500 ohms is assumed for the lines and 3,000 ohms for the power transformers, and if the arresters which do not come into play until the arrester gap breaks down are neglected, the incoming surge encounters a surge impedance all the way from about 125 to 430 ohms. This decrease in station surge impedance compared to the incoming line surge impedance will cause the voltage surge to decrease to four tenths to nine tenths of the incoming surge. If the incoming surge is assumed to be limited to 680 to 850 kv by the reduced line insulation or expulsion protector tubes, then the bus voltage will be reduced to about 275 to 765 kv by the station surge impedance. The basic-impulse insulation level[10] for 138-kv apparatus is 650 kv, and in some of the most favorable station arrangements a voltage well below this value is held by the station impedance alone.

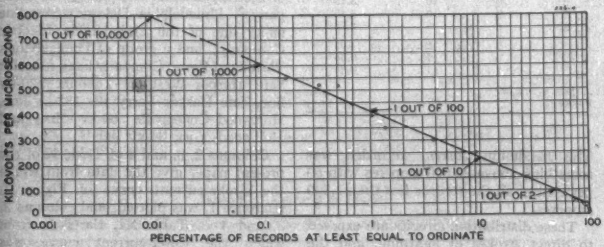

Figure 4. Rates of change of voltage at 132-kv stations of the Appalachian Electric Power Company, 589 records, 1939 to 1943, inclusive

Current in Overhead Ground Wires and Line Conductors and in Station Arresters

In Table VII are summarized the overhead-ground-wire currents measured near stations in 1940 to 1943, inclusive, a total of 133 readings. The maximum current recorded was 36,000 amperes with 50 per

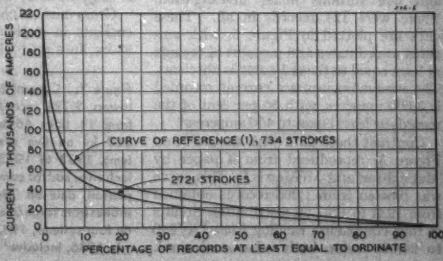

Figure 6 (right). Currents in lightning strokes; 2,721 records from 11 lines 66 to 220 kv on five systems, 1933 to 1943, inclusive, and for comparison, data on 734 strokes from seven lines on four systems, 1933 to 1936, inclusive[7]

Table VII. Overhead-Ground-Wire Current Near Stations, 1940–1943, Inclusive

Appalachian Electric Power Company 132-Kv System

Range of Current, Amperes	1940	1941	1942	1943	Total	No. at or Above Level	Percentage at or Above Level
500–1,000				20	20	133	100.0
1,001–1,500			2	0	2	113	85.0
1,501–2,000	24	12	0	5	41	111	83.6
2,001–3,000	6	6	0	9	21	70	52.6
3,001–4,000	3	0	2	4	8	49	36.8
4,001–5,000	3	0	3	5	11	41	30.8
5,001–6,000	1	1	2	1	5	30	22.5
6,001–7,000	0	0	0	0	0	25	18.8
7,001–8,000	0	0	2	1	3	25	18.8
8,001– 9,000	1	1	2	2	6	22	16.5
9,001–10,000	4	1	0	0	5	16	12.03
10,001–12,000	2	1	0	2	5	11	8.28
12,001–15,000	0	0	0	0	0	6	4.51
15,001–20,000	0	1	0	0	1	6	4.51
20,001–30,000	1		1	1	3	5	3.76
33,000	0		1		1	2	1.50
36,000	1				1	1	0.75
Total	45	23	15	50	133		
Maximum	36,000	17,200	33,000	27,500			

Table VIII. Line-Conductor Current at Stations, 1940–1943, Inclusive

Appalachian Electric Power Company 132-Kv System

Range of Current, Amperes	1940	1941	1942	1943	Total	No. at or Above Level	Percentage at or Above Level
500–1,000				43	43	290	100.0
1,001–1,500			30	0	30	247	85.2
1,501–2,000	65	23	0	14	102	217	74.8
2,001–3,000	29	20	19	11	79	115	39.7
3,001–4,000	3	7	3	6	19	36	12.4
4,001–5,000	1	1	2	3	7	17	5.86
5,001–6,000	0		0	0	0	10	3.45
6,001–7,000	2		0	0	2	10	3.45
7,001–8,000	2		0	3	5	8	2.76
8,001–9,000	1		1		2	3	1.04
9,001–10,000	0				0	1	0.35
11,500	1				1	1	0.35
Total	104	51	55	80	290		
Maximum	11,500	5,000	8,500	8,000			

cent of all records at least equal to 2,200 amperes.

In the four years 1940 to 1943, inclusive, 290 records were obtained of line-conductor current adjacent to stations. The data are given in Table VIII. The maximum current recorded was 11,500 amperes, and 50 per cent of all the records were at least equal to 1,800 amperes.

In Table IX are given the records of station-arrester current for the four years and five stations under investigation. There were 124 records in all. These data are plotted in Figure 5, with amperes as ordinates and per cent of records at least equal to the ordinates as abscissas. The maximum arrester current recorded is 3,600 amperes, with 50 per cent of the records at least equal to 400 amperes.

Contrast these data with the curve on Figure 5, reproduced from a paper by McEachron and McMorris.[8] This curve was plotted from 1,608 records obtained from 1934 to 1937 on distribution circuits of four companies, ranging from 120/240 to 24,000 volts, both urban and rural. The maximum current recorded was something above 25,000 amperes with 50 per cent of all the records less than 1,300 amperes.

These distribution circuits are exposed to direct strokes of lightning, and the arresters are as a rule near the stroke. On the other hand, the stations in our investigation are shielded from direct strokes and are only subject to traveling waves, so that the duty on the arresters is comparatively mild.

Gross and McMorris[9] have recorded currents in station arresters of 22- and 33-kv lines up to 12,000 and 15,000 amperes, with, however, 4,100 amperes maximum on 132-kv lines. Here again, the low-voltage lines probably are not equipped with overhead ground wires, and the conductors are exposed to direct strokes. The conditions therefore are more severe than on higher-voltage lines where the conductors and stations are shielded. The middle curve on Figure 5 is reproduced from reference 9 and is plotted from 459 records of station-arrester current on lines of the American Gas and Electric Company, ranging from 11 to 132 kv, obtained during the years 1936 to 1939, inclusive.

Hansson and Waldorf[14] report the results of an investigation of current in 26 banks of arresters at 66-, 132-, and 220-kv stations, during the years 1935 to 1942, inclusive. A total of 53 records was obtained, the maximum current being 7,400 amperes through one of the 66-kv arresters. Six per cent of the discharges exceeded 2,700 amperes, and 66 per cent were less than 1,000 amperes.

Lightning Current in Towers and Strokes

In Figure 1 of reference 1, cumulative curves of tower and probable stroke current were given for 734 strokes, occurring during the years 1933 to 1936, inclusive. These data were secured on the Wallenpaupack–Siegfried 220-kv line of the Pennsylvania Power and Light Company;[11] Glenlyn–Roanoke 132-kv line of the Appalachian Electric Power Company;[12] Philadelphia–Delaware Stateline 66-kv line of the Philadelphia Electric Company; and a group of Pennsylvania Water and Power Company lines, namely: Safe Harbor–Westport–Takoma 220-kv line, Safe Harbor–Perryville 132-kv line, Holtwood–Coatesville 66-kv line and Holtwood–York 66-kv line.[13]

Columns 2, 3, and 4 of Table X of the present paper give the data from which the stroke-current curve of Figure 1, reference 1, was plotted, and columns 2, 3, and 4 of Table XI, the data from which the tower-current curve was plotted.

Since 1936 a large amount of additional data have been accumulated on the Pennsylvania Water and Power Company's lines, including, in addition to the lines previously listed, the Safe Harbor–Riverside 220-kv, the Holtwood–Baltimore 66-kv, and the Philadelphia Road–Gunpowder 110-kv lines;[14] also, on the

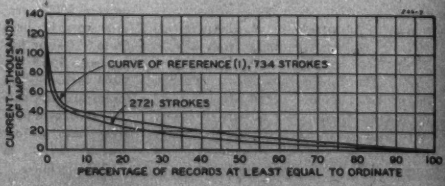

Figure 7. Currents in towers, 2,721 records from 11 lines 66 to 220 kv on five systems, 1933 to 1943, inclusive; and for comparison, data on 734 strokes from seven lines on four systems, 1933 to 1936, inclusive[1]

Table IX. Station-Arrester Current, 1940–1943, Inclusive

Appalachian Electric Power Company 132-Kv System

Range of Current, Amperes	1940	1941	1942	1943	Total	No. at or Above Level	Percentage at or Above Level
150–250	8	1	2	2	13	123	100.0
251–500	7	12	12	28	59	110	89.4
501–1,000	5	1	6	13	25	51	41.5
1,001–1,500	2	3	5	5	15	26	21.1
1,501–2,000	0	2	1	3	6	11	8.94
2,001–3,000	1	3			64	5	4.07
3,600		1			1	1	0.81
Total	23	23	26	51	123		
Maximum	2,100	3,600	1,700	1,950			

Table X. Currents in Lightning Strokes

Eleven Lines of Five Systems, 66 to 220 Kv, 1933 to 1943, Inclusive

1 Range of Current, Amperes	2 No. of Strokes in Range, 1933–1936[1]	3 No. at or Above Level, 1933–1936	4 Percentage at or Above Level, 1933–1936	5 No. of Strokes in Range, 1933–1943	6 No. at or Above Level, 1933–1943	7 Percentage at or Above Level, 1933–1943
1,000–5,000	72	734	100	567	2,721	100
5,001–10,000	121	662	90.2	611	2,154	79.2
10,001–20,000	167	541	73.7	640	1,543	56.7
20,001–30,000	115	374	51.0	296	903	33.2
30,001–40,000	92	259	35.3	227	607	22.3
40,001–50,000	62	167	22.8	140	380	14.0
50,001–60,000	30	105	14.3	80	240	8.82
60,001–70,000	24	75	10.2	61	160	5.88
70,001–80,000	8	51	6.95	22	99	3.64
80,001–90,000	11	43	5.86	22	77	2.83
90,001–100,000	6	32	4.36	11	56	2.06
100,001–110,000	5	26	3.54	11	45	1.65
110,001–120,000	5	21	2.86	9	34	1.25
120,001–130,000	7	16	2.18	9	25	0.918
130,001–140,000	5	9	1.23	7	16	0.588
140,001–150,000	0	4	0.545	2	9	0.331
150,001–160,000	2	4	0.545	3	7	0.257
160,001–170,000	0	2	0.273	0	4	0.147
170,001–180,000	0	2	0.273	1	4	0.147
180,001–190,000	0	2	0.273	0	3	0.110
190,001–200,000	1	2	0.273	1	3	0.110
200,001–210,000	0	1	0.136	0	2	0.073
213,400	0	1	0.136	1	2	0.073
218,000	1	1	0.136	1	1	0.037
Total	734			2,721		
Maximum negative	218,000			218,000		
Maximum positive	193,000			212,000		

Table XI. Currents in Towers

Eleven Lines of Five Systems, 66 to 220 Kv, 1933 to 1943, Inclusive

1 Range of Current, Amperes	2 No. of Currents in Range, 1933–1936[1]	3 No. at or Above Level, 1933–1936	4 Percentage at or Above Level, 1933–1936	5 No. of Currents in Range, 1933–1943	6 No. at or Above Level, 1933–1943	7 Percentage at or Above Level, 1933–1943
1,000–5,000	78	734	100	617	2,721	100
5,001–10,000	182	656	89.4	816	2,104	77.6
10,001–20,000	171	474	64.6	589	1,288	47.3
20,001–30,000	133	303	41.3	300	699	25.7
30,001–40,000	110	170	23.2	248	399	14.7
40,001–50,000	33	60	8.2	81	151	5.55
50,001–60,000	11	27	3.7	35	70	2.57
60,001–70,000	7	16	2.2	21	37	1.36
70,001–80,000	4	9	1.22	5	16	0.588
80,001–90,000	0	5	0.68	4	11	0.404
90,001–100,000	3	5	0.68	5	7	0.257
100,001–110,000	0	2	0.27	0	2	0.074
110,001–120,000	1	2	0.27	1	2	0.074
120,001–130,000	0	1	0.14	0	1	0.037
132,000	1	1	0.14	1	1	0.037
Total	734			2,721		
No. negative	685			2,235		
No. positive	49			486		
Maximum negative	132,000			132,000		
Maximum positive	100,000			100,000		

100-kv Shoshone–Denver line of the Public Service Company of Colorado.[2] For the Pennsylvania Water and Power Company's lines data up to and including 1942 are available, and for the Public Service Company of Colorado line up to and including 1943. Including the original 734 strokes, data are now available on 2,721 strokes. These data are summarized as to stroke currents in columns 5, 6, and 7 of Table X, and as to tower currents in columns 5, 6, and 7 of Table XI.

In Figure 6 are plotted the stroke-current curve of reference 1 (column 4, Table X, 734 strokes), and the stroke-current curve of column 7, Table X, 2,721 strokes; and in Figure 7 the tower-current curve of reference 1 (column 4, Table XI, 734 strokes), and the tower-current curve from column 7, Table XI, 2,721 strokes.

In reference 1, the average of each 10,000-ampere range was plotted as ordinate, whereas in the present paper the lower limit of each range is plotted. It will be noted that the new curves fall somewhat under the old curves.

In the data of reference 1, of the 734 strokes 685 or 93.3 per cent were negative, and 49 or 6.7 per cent were positive. In the more extensive data of the 2,721 strokes, 2,235 or 82.1 per cent were negative and 486 or 17.9 per cent positive.

The maximum negative-stroke current in both the old and present data was 218,000 amperes. The maximum positive-stroke current in the old data was 193,000 amperes, and in the more extensive data 212,000 amperes. The maximum current in individual towers in both the old and present data is 132,000 amperes negative, and 100,000 amperes positive. While the percentage of positive strokes is small, occasionally there is a positive stroke of very high magnitude.

Distribution of Current in Counterpoise and Driven Rods

In a paper by the present authors, in collaboration with J. G. Hemstreet,[3] a comparison was made between the current picked up under lightning-surge conditions by driven rods and by counterpoise wires, both parallel to the line and at right angles to the line. The results of

Table XIA. Current Pickup at Towers 7717, 7716, and 7718

Tower No.	Right-Angle Counterpoise, Amperes	Driven Rod, Amperes
7716	0*	3,400
7717	5,200	14,300
7718	2,300*	9,600
Total	7,500+	27,300

* Link missing on east side of tower.

six strokes to the Consumers' Power Company 140-kv *N*-14 line occurring in the years 1937 to 1941, inclusive, were analyzed. In the years 1942 and 1943 three additional strokes took place to this line. These will be discussed briefly.

Stroke 14. Some time prior to May 5, 1942, a stroke hit the ground near tower 7666 in section *A*, equipped with parallel continuous counterpoise and right-angle counterpoise. Current flowed into the stroke over the continuous counterpoise and overhead ground wire from two spans each side of tower 7666. At tower 7666 the following conditions prevailed:

Toward tower 7666:

From overhead ground wire	8,600 amperes
From continuous counterpoise	7,300 amperes
From right-angle counterpoise	1,000 amperes
Total	16,900 amperes
Away from tower 7666:	
In west right-angle counterpoise toward stroke to ground	—16,000 amperes

Similar occurrences have been noted from time to time on the Pennsylvania Power and Light Company 220-kv line and the 100-kv line of the Public Service Company of Colorado. The transmission system, that is, overhead ground wire and counterpoise or counterpoise alone, has acted as a carrier to gather in the current for the stroke at one side of the transmission line.

Stroke 15. This stroke occurred in April 1943 in section *C*, equipped with right-angle counterpoise and driven rods. The stroke contacted the overhead ground wire just north of tower 7717, and current was picked up and fed into the stroke at this tower and the adjacent towers 7716 and 7718. Table XIA shows the current pickup at these towers.

As in the previously reported strokes, the driven rod picked up about 80 per cent of the current, with the other 20 per cent coming in on the right-angle counterpoise.

Stroke 16. This stroke occurred on September 6, 1943, in section *C* (right-angle counterpoise and driven rods). The stroke occurred to the overhead ground wire between towers 7717 and 7718, and the overhead ground wire brought in current from a distance of five to six towers each side of the point of stroke. The total pickup by the counterpoise and driven-rod system was about 111,000 amperes, of which 82,000 amperes, or 74 per cent, came in by way of the driven rods, and 29,000 amperes, or 26 per cent, by way of the right-angle counterpoise, neglecting the small amount via the tower footings.

Voltage Gradient in Vicinity of Towers

There were no strokes in 1942 to the section of the 140-kv *T*-20 line of the Consumers' Power Company equipped to measure voltage gradient in the vicinity of towers. Two strokes occurred in this section on September 6, 1943, stroke 17 to the overhead ground wire between towers 4405 and 4406 and stroke 18 at tower 4411. Readings were obtained at five towers in each stroke, but good correlation between tower current and the potential from tower to probe rod six feet away from the tower was secured only at two towers in stroke 18.

Table XII repeats the information for six strokes and nine towers first given in Table XVI of reference 3, and also gives the information for the two towers in stroke 18. In addition, there are given data for eight towers in strokes 7 and 8, in which the readings of voltage between the tower and probe rod were uncertain, because the lightning-stroke-recorder film flashed over. However, since we know the flashover voltage of the film, we can put this voltage down as a minimum value and figure out the ratio of R_s/R_n, knowing that the actual ratio is somewhat greater than the value given. Data also are included on one additional tower for stroke 7 and two additional towers for stroke 11, which were omitted previously, because the lightning-stroke-recorder reading in each case was just a trace. Values of five and seven kilovolts have been assigned to the traces and the readings included.

This gives a total of 22 readings, which can be considered good data or supporting data. Seventy-seven readings were rejected because either the current or voltage readings were missing or doubtful.

Figure 2 of reference 3 is redrawn as Figure 8 in this paper, with the nine original points, five additional good points, and eight points which are uncertain as to ratio of R_s/R_n, except that we know the ratio is greater than the plotted value. The drawn curve is actually the same as that given in Figure 2 of reference 3, the additional points only serving to tie the curve down a little more firmly.

Table XII. Surge Resistance of Tower Footings

Consumers Power Company 140-Kv, *T*-20 Line

1 Date	2 Stroke No.	3 Tower No.	4 R_N, Tower-Footing Resistance, Ohms	5 I_T Total Tower Current, Amperes	6 $R_N I_T$, Tower Potential (4)x(5), Kv	7 V_M, Tower-to-Probe Potential, Kv	8 V_T, Tower Potential, (7)x(2.5) Kv	9 R_S, Surge Resistance, (8)/(5), Ohms	10 R_S/R_N, (9)/(4), Ratio
		4393	33	2,000	66	7	17.5	8.75	0.265
		4394	35	6,000	210	27	67.5	11.25	0.322*
		4395	51	3,000	153	30+	75+	25 +	0.49 +
9/15/1936	7	4396	56	2,300	129	30+	75+	32.6 +	0.582 +
		4403	1,260	9,200	11,592	40+	100+	10.88+	0.0086+
		4404	816	12,900	10,526	40+	100+	7.77+	0.0095+
		4405	1,187	12,300	14,600	40+	100+	6.86+	0.0058+
		4408	75	7,700	578	30+	75+	9.75+	0.13 +
		4407	266	9,500	2,527	100+	250+	26.35+	0.099 +
6/4/1937	8	4408	76	50,000	3,750	100+	250+	5 +	0.067 +
		4410	15	3,300	50	5	12.5	3.8	0.254*
5/27/1938	9	4408	75	11,700	878	190	475	40.6	0.542*
5/27/1938	10	4400**	1,299	13,700	17,796	280	700	51.1	0.039*
		4401	942	6,800	6,406	170	425	62.5	0.066*
		4392	22	2,000	44	5	12.5	6.25	0.284
		4393	33	3,400	122.2	5	12.5	3.68	0.112
5/27/1938	11	4394	35	6,600	231	40	100	15.15	0.433*
		4395	51	16,000	816	170	425	26.6	0.522*
		4396	56	11,000	616	140	350	31.8	0.568*
7/30/1940	13	4412	13	45,600	593	222	555	12.15	0.935*
9/6/1943	18	4411	14	10,400	145.6	18.0	45	4.33	0.31
		4412	13	11,900	154.7	37.8	94.5	7.95	0.612

Total tower current (column 5) assumed 1.5 times measured current in tower legs, to take care of cross-member current.

* From Table XVI of reference 3. ** Flashover all three phases.

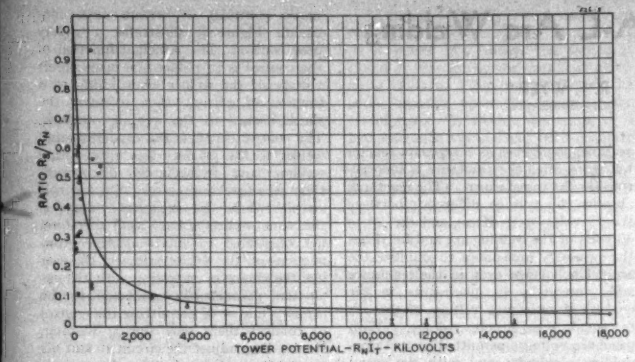

Figure 8. Ratio of surge resistance during natural lightning strokes to normal tower-footing resistance plotted against product of current and normal footing resistance

○ (9) Original points, Figure 2, reference 3
● (5) Additional good points
ŏ (8) Points which are probably low because lightning-stroke recorder flashed over

Additional probe rods were driven in 1943 at a distance of 12 feet from the tower. These, like the original rods six feet from the tower, were driven five feet deep. Lightning-stroke recorders were mounted on the first set of probe rods and coupled by voltage divider between the rods, so that surge voltages between the rods would be read.

Two good records were obtained in 1943. Several other simultaneous readings were obtained of voltage between tower and first probe rod and between first and second probe rods, but no readings or uncertain readings of tower current. No attempt will be made to analyze these readings until further reliable data have been accumulated.

Conclusions

1. Rate of change of voltage has been measured at five stations on the 132-kv system of the Appalachian Electric Power Company over a five-year period. The highest measured rate of change was 550 kv per microsecond, with 50 per cent at least equal to 100 kv per microsecond. These data should have an important bearing on fixing a reasonable front-of-wave test for apparatus.

2. Voltages up to 525 kv were measured on 132-kv station busses over a four-year period. This voltage is limited by the line and bus insulation, the lightning arresters, and the station surge impedance.

3. Currents up to 36,000 amperes were measured in overhead ground wires near stations and up to 11,500 amperes in line conductors of 132-kv lines over a four-year period. On a well shielded line, direct strokes are intercepted by the overhead ground wires, and current gets onto the conductors only through flashover of the line insulators or the protective tubes. The conductor-current magnitude is further modified by the outgoing lines and arresters.

4. Currents up to 3,600 amperes were measured in station arresters on 132-kv lines over a four-year period. This value should be contrasted with a current of 25,000 amperes measured in distribution-circuit arresters,[8] and 15,000 amperes in low-voltage-transmission-circuit arresters.[9] It appears that in stations with well-shielded incoming lines both voltage and current magnitudes are of very moderate values.

5. Stroke-current and tower-current data are available from 11 lines of five companies, gathered during a period of 11 years and totaling 2,721 strokes. The maximum stroke current was 218,000 amperes and the maximum tower current 132,000 amperes. Of the total strokes 82 per cent were negative and 18 per cent positive.

6. A few additional readings are available from the setup on the 140-kv system of the Consumers' Power Company, designed to evaluate the surge resistance of towers. These data tend to anchor somewhat more firmly the curve first given as Figure 2 of reference 3 and to reinforce the conclusions previously drawn that the ratio of surge tower-footing resistance to normal tower-footing resistance decreases with increased current and increased resistance, and that this ratio may be as low as 0.04 for the sandy soil conditions and the magnitude of resistance and current encountered.

A paper by I. W. Gross and G. D. Lippert gives further details of the investigation on the American Gas and Electric Company system;[15] another recent paper is pertinent to our present investigation in that it discusses the impulse characteristics of various types of soils and electrodes.[16]

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Power Supply for A-C Arc Welding

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THE rapid growth of a-c arc welding in the last ten years has resulted in a-c welding becoming a large fraction of all arc welding rather than a negligible proportion. As power loads due to a-c arc welding become larger, questions arise in the minds of users and power-supply authorities about power requirements of a-c welders and the effect of a-c welders on power circuits. In some instances arc welding has been confused with resistance welding, although the two are entirely different from the standpoint of power supply. This paper presents data useful for determining the effects of a-c arc-welding loads on electric power circuits.

A-c arc welders may be divided into two general types—industrial welders and utility welders. For industrial service, welders must be suitable for high-speed high-quality welding, must be designed for quick and easy arc starting, and must be usable with long welding leads. This requires fairly high open-circuit voltage for easy arc starting and stability of current. Industrial welders generally include capacitors for power-factor correction. Utility welders are built in low-current ratings, usually 200 amperes and below and are characterized by low open-circuit voltage, low kilovolt-ampere demand, simplicity of construction, and low cost. They are intended for use in small shops for repair work where their slow arc starting, slow operation, and current variation with arc length are not too objectionable.

High - reactance transformer - type single-operator welders are used almost universally for a-c welding. They are two-winding transformers, not autotransformers, for obvious reasons of safety. A-c arc welders are rated in terms of welding amperes rather than kilovolt-amperes.

Industrial-Duty Welders

Industrial-duty welders are built for primary power circuits of 220-, 440-, or 550-volt rating and step down the voltage to approximately 75. Although voltages as high as 100 have been used, industrial-duty welders generally range from 70 to 80 volts open circuit. Included in the welder is an adjustable reactance, sometimes as a separate reactor but more often the reactance is incorporated in the transformer. The reactance absorbs the voltage difference between the 75 volts open circuit and the 20 to 40 volts of the welding arc and furnishes the necessary impedance to stabilize the arc. The voltage drop in the reactance adds vectorially in quadrature to the equivalent resistance voltage of the arc to equal open-circuit voltage. With usual arc voltages permitted by metallic-welding electrodes and with the usual open-circuit voltages, the reactance voltage is 75 to 85 per cent of open-circuit voltage and, during the start of a weld with the electrode short-circuited, is equal to 100 per cent. Adjustment of the reactance therefore permits accurate control of welding current because the reactance is the largest impedance in the circuit.

The usual ampere ratings for industrial hand welding are 200, 300, 400, and 500 amperes. The usual range of output is from 20 per cent to 125 per cent of the rating. The adjustment above 100 per cent not only permits occasional short jobs to be done at higher than rated current, but, even more important, it permits welding to be done at rated current with welding leads as long as 150 feet.

Figure 1 shows a simple equivalent circuit of an arc-welding transformer. The capacitors, shown dotted, generally are included in heavy-duty industrial welders to improve power factor and reduce current demand from the primary circuit. The vector diagram of primary voltage and current in an a-c arc welder illustrates the effect of capacitors in reducing current and improving power factor. Figure 2 shows kilovolt-ampere input and power factor of 300-ampere a-c welders with and without power-factor correction.

Welders with built-in power-factor correction generally are designed to operate at 0.75 to 0.85 power factor at rated load. The power factor becomes unity at approximately half load, and the primary current is leading at lighter loads and at no load. This leading current is often useful for improving the over-all power factor of the primary circuit when other low-power-factor equipments such as motors are connected to the same circuit.

Where large numbers of high-power-factor welders are connected to a single circuit and where welding loads are such that the majority operate idle or lightly loaded, the total leading current may become undesirably high. In such cases automatic voltage-reducing controls (Idle-matic controls) of certain types are useful. Figure 3 illustrates a widely used control. The principal function of the control is to reduce the open-circuit voltage of the welder when idling to a fraction of normal, thus reducing the shock hazard to the welding operator. The control connects the capacitors and welder to the primary line only during welding and immediately disconnects them when welding ceases. On 440-volt circuits where the capacitor voltage is the same as line voltage and, therefore, not connected to autotransformer connections on the welder primary, the user has the choice of operating with the capacitors permanently connected to the primary line or of permitting the control to connect them only during welding. He can thus adjust the circuit to suit his operating conditions. The data given later in the paper under duty factor may be used as a guide to determine the preferable connection.

Figure 4 shows secondary volt-ampere curves of a typical industrial a-c arc welder. Each curve applies for one setting of the control reactance. Most industrial welders have stepless adjustment of reactance so that there is an infinite number of these curves between minimum and maximum.

Effect of Primary-Voltage Variation

A-c welder rated input current and kilovolt-amperes are based upon operation at rated primary voltage: 220, 440, or 550 volts. Many industrial circuits actually operate at average levels higher than these nominal values, often at 110 per cent. Figure 5 shows how the primary kilovolt-ampere input is increased by overvoltage. The curves are based on maintained rated secondary load. The arc voltage will stay constant as determined by the electrode and length of arc, but with increasing primary voltage it will be necessary to readjust the current control to prevent current from increasing. With constant secondary cur-

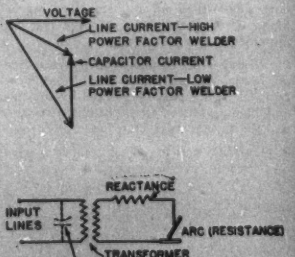

Figure 1. A-c-arc-welder equivalent circuit and vector diagram

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rent the transformer primary current also must stay constant except for the small effect of the increased exciting current required by the transformer core. Therefore, the kilovolt-ampere input to a low-power-factor welder increases as the primary voltage increases, the increase being principally the extra reactive kilovolt-amperes required to absorb the difference between the fixed-load voltage and the higher open-circuit voltage. In a high-power-factor welder the capacitor kilovolt-amperes increase as the square of the voltage and more than balance the increase of inductive kilovolt-amperes so that the current input decreases as the voltage increases.

No-Load Switching Transients in A-C Arc Welders

Figure 6 shows transient primary voltages and currents which occur when applying or removing excitation with no load on the secondary circuit. These tests were made on a standard welder rated 550 primary volts, 500 amperes secondary current, rated welder with and without power factor correcting capacitors. Switching was done with a standard 600-volt safety switch of snap-action type. Power supply was one-phase of a 550-volt two-phase 60-cycle 600-kva shop circuit used principally for power supply to motor-driven machine tools in a machine shop. The impedance of the supply circuit was such that the voltage drop at the welder primary terminals, when loaded at 500 amperes secondary current, measured approximately two per cent.

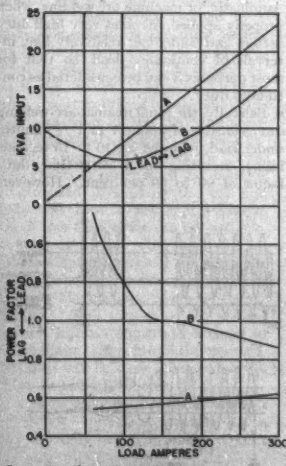


Figure 2. Input kilovolt-amperes and power factor of an industrial 300-ampere a-c welder at standard 40-volt load

A—Low-power-factor welder
B—High-power-factor welder

An inrush surge of exciting current occurs when any transformer is switched on a power line, unless the switch is closed at very nearly the instant of maximum voltage. The magnitude of the surge depends upon the design of the transformer. A welder consisting of a low-reactance transformer with separate secondary reactor may have very large instantaneous-current surges up to perhaps 20 times normal primary-load current. High-reactance transformers generally draw low inrush currents due to the high reactance of the primary winding. The highest crest current measured on the high-reactance welder previously referred to was two times the crest of normal rated current, although calculations indicate as much as three times might occur, if the circuit were closed at exactly voltage zero. Inrush-current peaks of this magnitude die down rapidly and have usually no noticeable effect on the primary circuit. They cause much less voltage drop in primary circuits than the starting of an equivalent motor.

When a high-power-factor welder is switched on the line, a surge current may flow in the capacitors as shown in the oscillogram of Figure 6B. Currents approaching five times normal have been measured, but the duration of the current flow is so short—generally less than 0.001 second—that the effect on the primary circuit is negligible. Instantaneous overvoltages of 25 per cent above normal have been measured of the same short duration.

Switching-off excitation of a low-power-factor welder may result in a transient-voltage rise as will be seen in Figure 6A. This voltage depends upon the speed at which the switch can interrupt the exciting current. High-speed snap-action switches may cut off current so rapidly that the inductive kick can cause considerable voltage rise. A rise 84 per cent above normal was measured on this welder.

Oscillograms of switching-off excitation from a high-power-factor welder show that, as would be expected, the capacitors completely eliminate overvoltage. (See Figure 6B.) The energy storage capacity of the capacitors is so high that any stored inductive energy in the transformer core cannot affect the capacitor voltage measurably. After removal of excitation, the capacitors discharge slowly through the transformer winding, oscillating at a decreasing frequency because of the nonlinear characteristic of the transformer core.

Switching of Arc Welders When Loaded

Starting and finishing a weld switches the load on the secondary side of the welder. It will be seen from the curves of Figure 4 that a reactance-controlled industrial welder limits the short-circuit current at the start of a weld to a value

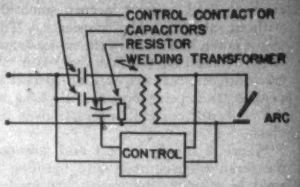


Figure 3. A-c arc welder with automatic voltage-reducing (Idlematic) control

not much higher than normal welding current. There also may be a transient overcurrent for one or two cycles of the type caused by switching a reactive load on an a-c line. However, the resistance of the electrode, its contact resistance, and the resistance of the welding cable and transformer are large enough to hold the transient overcurrent to a low value, usually much less than 1.5 times the steady-state current. Therefore, starting a welding arc does not result in large current surges. A typical oscillogram of welding current and arc voltage in Figure 7 shows that neither starting nor extinguishing a welding arc causes objectionable transients. Starting the arc can cause momentary currents seldom exceeding approximately 1.5 times normal. Extinguishing the welding arc by withdrawing the electrode is a slow process requiring several cycles, so that the current and voltage in the reactance decrease gradually and no overvoltage occurs.

The additional oscillograms of Figure 8 show primary and secondary voltages and currents occurring when a welding arc is started and stopped at various loads. Figure 8A shows start and finish of a 300-ampere welding load on a low-power-factor welder. Figure 8B shows a 500-ampere load on a high-power-factor welder. Figure 8C is included to show that at loads less than half rating the load current of a high-power-factor welder may be less than no-load current. This also is shown by the curves of Figure 2. As will be seen from these oscillograms, the transition from leading no-load cur-

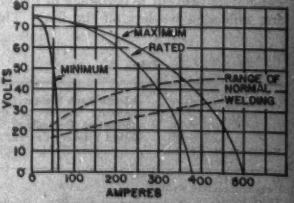


Figure 4. Output volt-ampere curves of 300-ampere industrial welder

rent to load current occurs smoothly without objectionable transients. The slight notch in the top of the no-load current is caused by the fact that, as in all transformers, the core exciting current is peaked, and, being opposite in phase to the capacitor current, subtracts from its crest.

Figure 9 shows current and voltages measured when starting and finishing a weld in a high-power-factor arc welder with Idlematic control. The action of the control is illustrated clearly by these oscillograms. Before starting the weld the contactor is open, leaving the capacitors and the welder primary winding disconnected. The welder secondary is excited from the control at reduced voltage —approximately 30 volts. When the electrode is touched to the work, the welder secondary voltage becomes nearly zero, and the control voltage is impressed on the contactor coil. When the contactor closes, it connects the welding load and the capacitors simultaneously to the line. The control is designed so that the contactor holds in, as long as welding load is maintained. When the welding arc is extinguished, normal open-circuit voltage appears on the secondary circuit for about two cycles at which time the contactor drops out disconnecting the capacitors and welder primary and reducing secondary voltage to normal idling voltage. The capacitors are discharged automatically through a discharge resistor. Overvoltage from switching off the welder exciting current is prevented by the control circuit which connects the welder secondary terminals to a resistor before disconnecting the welder primary terminals.

The two oscillograms in Figure 9 were not taken at the same time or set up, which accounts for the different scales of voltages and currents. The somewhat rounded top of the secondary voltage in the first oscillogram is caused by the impedance voltage drop in the long secondary leads used in this test, as voltage measurement was made at the transformer not at the arc. The actual wave shape of any a-c metallic-welding arc voltage is very flat-topped.

Effect of Power-Factor-Correcting Capacitors on Primary Switches

Tests previously described indicate that capacitors prevent overvoltage in switching unloaded welders off the line. This would indicate that the interrupting duty on the switch is reduced by the presence of the capacitors. Although no comparative tests are available on loaded welders, the following facts may be indicative: There have been reported instances of primary-switch failure on low-power-factor welders occurring when the welding electrode froze to the work, maintaining a secondary short circuit, which had to be interrupted by opening the primary switch. In this case the load voltage is zero and the power factor of the primary current is very low—five to ten per cent. Therefore, the inductance built into the welder for the purpose of making the welding arc stable makes the arc in the switch very difficult to interrupt. On the other hand, a series of tests made on several types of commercial horsepower-rated switches connected to a short-circuited power-factor-corrected welder indicated that the switches cleared the circuit with less disturbance than was normal for the same current and power factor without capacitors. Apparently, the capacitors hold switching-surge voltages so low that they lessen switch interrupting duty considerably.

Capacitor current itself is interrupted easily by a switch. Capacitor-current surge on closing the switch has not been found to cause trouble, as switches used with arc welders are capable of closing on several times as much current as that caused by the amount of capacitance used in a welder.

Table I

Numbers of Welders	Add for Each Welder, Line Capacity Equal to the Following Percentage of Rated Primary Current of One Welder
First and second welder	100
Third welder	85
Fourth welder	70
All additional	60

Effect of Capacitors on Externally Caused Surge Voltages

Switching-surge overvoltages occur on all types of electric power circuits, but they are of comparatively high frequency and extremely short duration—a few thousandths of a second. Although no evidence is available to indicate that they present a shock hazard to the welding operator, it is interesting to note that the power-factor-correcting capacitors on a welder present a very effective barrier to high-frequency voltage.

Phase Unbalance

The question of phase unbalance due to the application of single-phase welding transformer loads occasionally is encountered. This is usually an academic question; cases where phase unbalance from this source have proved actually troublesome are very rare. Perhaps the interest in this question arises from confusion of a-c arc welders, having relatively low kilovolt-ampere input, with resistance welders having relatively large kilovolt-ampere input. A good rule of thumb says that even without the balancing effect of polyphase motors running on the same line, no troublesome voltage unbalance will occur, if the kilovolt-ampere input to the arc-welding transformer does not exceed approximately half the kilovolt-ampere rating

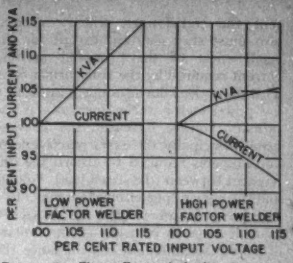


Figure 5. The effect of higher-than-rated input voltage on a-c arc welders operating at rated current

of the three-phase distribution-transformer bank to which it is connected. When a number of a-c welders are supplied by a polyphase line, they may be connected to different phases in order to balance their load, except when the transformers are to be operated in parallel.

Duty Factor

The arc-welding duty cycle varies widely, not only from plant to plant, but also from hour to hour in the same plant. (In this paper the term "duty cycle" will mean a group of specified intervals of arc time and idle time; for example, five minutes on and five minutes off. Duty factor is the ratio of arc time to the total time under consideration.) The majority of welders are used in manual-welding duty, and the following comments are confined to this class of service. Automatic, or machine arc welding, when properly applied, involves very high duty factors and sometimes relatively long intervals of continuous load, so that for most purposes it can be considered as continuous duty.

Basically, the usual manual-arc-welding duty consists of about 1 to $1^1/_2$ minutes under load, followed by 10 to 15 seconds idling, resulting in a short-time duty factor of 80 to 90 per cent. However,

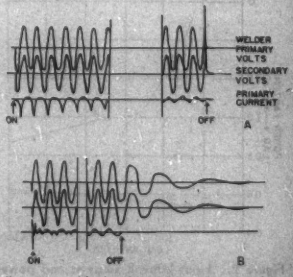


Figure 6. No-load switching of arc-welding transformers

A—Low-power-factor welder
B—High-power-factor welder

this cycle is rarely repeated more than eight or ten times before a longer idling interval takes place, so that all-day duty factors may run as low as ten per cent or as high as 50 or 60 per cent, depending on the nature of the work.

Advantage may be taken of these facts in providing electric service for groups of arc welders. Table I lists a conservative method of calculating primary-line capacity to supply a group of welders.

This table is usable for either low-power-factor welders or power-factor-corrected welders, using in either case the actual primary current input when delivering rated welding current. Wiring according to this table will carry, without being overloaded, the current from 50 per cent of welders operating at full load and 50 per cent idling, when low-power-factor welders are used, and will carry the current from 60 per cent of the welders at full load and 40 per cent idling, when power-factor-corrected welders with permanently connected capacitors are used.

Table I also can be used when welders are distributed among the phases of a three-phase circuit by the following procedure: Consider each group of three welders connected to the three phases as a single unit of current rating 1.73 times the primary rating of an individual welder and use the table as though the three were a single welder.

A single high-power-factor welder without Idlematic control, or its equivalent, will draw considerable leading-power-factor kilovolt-amperes while the welder is idling. The maximum 15-minute kilovolt-ampere demand will depend to a considerable extent on the duty factor, as well as on the amount of the capacitive kilovolt-ampere drawn by the capacitors, since it will involve a base load drawn by the capacitors during idling, plus intervals of somewhat higher kilovolt-ampere load during actual welding. The peak demand of a single welder will occur during the very short intervals when the welder is short-circuited in striking the arc and usually will have a maximum possible value of less than twice the kilovolt-ampere input at normal rated load.

When idlematic control is used, the capacitors usually are switched off, along with the welder primary, whenever the arc is broken. This eliminates the no-load capacitive kilovolt-ampere as a factor in the maximum kilovolt-ampere demand, which then will be some lower value, depending on the duty factor.

If a large number of welders without power-factor correction operate as a group, diversity begins to influence both maximum demand and peak demand. Figure 10 shows the shape of the welding-load curve for a group of 238 operators in a shipyard. (The recording ammeter from which this curve was derived actually measured one-seventh of the total load, which accounts for the relatively low currents indicated.) The average load was one-quarter of the connected load, indicating an average all-day duty factor of 25 per cent. (In this case connected load is assumed to be the total rated input of the number of welders equal to the number of operators working that day.) The 15-minute maximum demand was 26 per cent of the connected load, and the short-time peak indicated on the original ammeter record was only 30 per cent of the connected load.

Studies of the load imposed by smaller groups of welders show that diversity may be expected to reduce the 15-minute maximum demand drastically when more than four or five units are operating. Five units may have only 77 per cent as much maximum demand per unit as a single machine, and 20 units only 65 per cent as much.

Likewise, the peak short-time demand per unit will be reduced when sufficient numbers of welders are involved. In one case it was found that the expected peak demand per unit began to decrease when the number of welders reached six or seven and decreased fairly uniformly to about 80 per cent of the single-unit peak demand when 50 welders were included in the group.

With high-power-factor welders not equipped with Idlematic control, it is possible that the maximum demand may be the capacitive no-load kilovolt-amperes of the machines. Unless the duty factor is unusually high, the maximum demand of the group when operating under load will be reduced, because the leading kilovolt-amperes of those units which are idling will cancel all or a part of the lagging kilovolt-amperes drawn by the loaded units. But the capacitive kilovolt-amperes of the entire group may be drawn all at once during meal hours or rest periods, and this frequently will be the determining factor in the 15-minute maximum demand. The peak demand per unit will be reduced slightly (at normal duty factors) by the leading kilovolt-amperes of idling units.

Power Factor

In the matter of power factor to be expected from groups of high-power-factor welders, duty factor again plays an important part. Unless the capacitors are disconnected automatically when welding stops, the capacitive kilovolt-amperes of the idling units is available to improve the power factor of the system on which they are connected.

Figure 11 illustrates how power factors on various feeders will vary, depending on whether or not the capacitors are switched off at no load. These data are calculated for current designs of 300-ampere welders, the a-c units being equipped with ten kilovolt-amperes in capacitors and the d-c units being ordinary three-phase motor-driven generator sets without power-factor correction. In the calculations the welders are assumed to be operating on a load of 200 amperes at 30 volts with a 45 per cent duty factor. If the duty factor were higher, the power factor of the d-c units would be higher and that of the a-c units more lagging.

By comparing the figure for feeders *A*

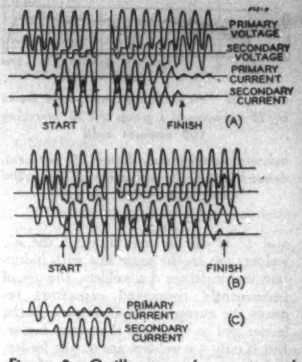


Figure 8. Oscillograms of currents and voltages during start and finish of a-c arc welds

A—300-ampere weld on a low-power-factor welder

B—500-ampere weld on a high-power-factor welder

C—150-ampere weld on a 500-ampere high-power-factor welder

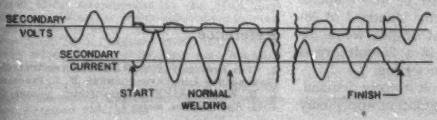


Figure 7. Secondary voltage and current in a-c arc-welding transformer

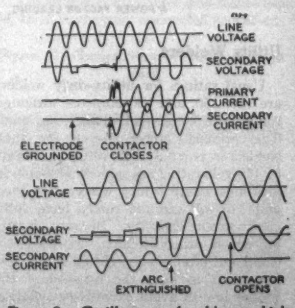


Figure 9. Oscillograms of weld on a high-power-factor welder with automatic voltage-reducing (Idlematic) control

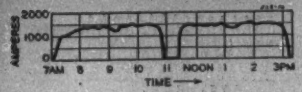
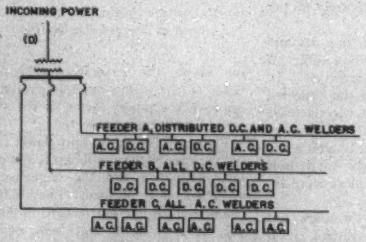


Figure 10. Arc-welding-current load drawn by 35 operators of a group of 238, averaging 160 amperes each

Indicated average-duty factor 25 per cent, demand factor 26 per cent, peak demand 1,700 amperes (30 per cent)

and *C*, it can be seen that, if the a-c welders are on the same line with induction-motor-driven d-c welders, the use of permanently connected capacitors reduces the average kilovolt-amperes in the feeder and so improves the power factor. But if only a-c welders are on the feeder, then automatic disconnection of the capacitors is preferable. The latter is also true from the point of view of the total load drawn by all three of the feeders illustrated.


INCOMING POWER
(D)
FEEDER A, DISTRIBUTED D.C. AND A.C. WELDERS
A.C. D.C. A.C. D.C. A.C. D.C.
FEEDER B, ALL D.C. WELDERS
D.C. D.C. D.C. D.C. D.C.
FEEDER C, ALL A.C. WELDERS
A.C. A.C. A.C. A.C. A.C. A.C.

AVERAGE K.V.A. INPUT AND POWER FACTOR

		FEEDER A		FEEDER B		FEEDER C		SUBSTATION (D)	
WITH CAPACITORS PERMANENTLY CONNECTED	LOAD	k.v.a. 33.	p.f. 0.91	k.v.a. 66	p.f. 0.6	k.v.a. 32.	p.f. 0.67N	k.v.a. 99.	p.f. 0.91
	NO LOAD (NOON HOUR)	12.	0.90	53.	0.34	60.	0*	34.	0.90
WITH AUTOMATIC DISCONNECTION OF CAPACITORS	LOAD	42.5	0.89	66.	0.60	21.	0.9	127.5	0.89
	NO LOAD (NOON HOUR)	26.5	0.34	53.	0.34	0		79.5	0.34

* POWER FACTOR LEADING

Figure 11. Typical load conditions on feeders supplying 300-ampere welders operating at 200 amperes 30 volts, 0.45 duty factor from one load-center substation

Utility Welders

Usual ratings for utility-duty welders are 100, 150, and 200 amperes, although some, both larger and smaller, are used. The primary power source for such welders is generally 230 volts, as circuits of 460-volt rating are seldom available in locations where utility welders are used and 115-volt circuits rarely have sufficient current capacity. Because circuits on which utility welders are used are small and often serve lighting loads, it is important to keep the demand of the welder low to avoid excessive regulation and flicker of lights. Heating of power supply circuits and transformers seldom will be important because of the intermittent nature of the load. These factors indicate that the first principle in design of utility welders should be lowest possible primary kilovolt-ampere demand. Also, it is desirable to keep the power factor high. The use of very low open-circuit voltage accomplishes both ends by reducing the kilovolt-ampere demand and by increasing the ratio of arc voltage to open-circuit voltage, thus increasing the power factor. Open-circuit voltages in the range of 40 to 60 volts are adequate for maintenance of a stable welding arc at low currents with present-day heavily coated a-c welding electrodes, although arc starting may be difficult and time-consuming, particularly when welding on clean smooth sheet steel. Another desirable design feature is strict limitation of the maximum obtainable output to prevent overload on the power circuit. The overtravel of current adjustment normally included in industrial welders is not necessary in utility welders, because there is less need for long welding leads and high output. Large welds for repair of heavy metal sections always can be made by multiple passes.

The characteristics of a design which might be suggested by the preceding discussion are shown in Figure 12. Such a welder would be suitable for operating standard one-eighth-inch a-c steel welding electrodes, and thus would be suitable for most repair welding. Its nominal rating probably would be 100 amperes based on the customary standard of 30-volt arc. The actual output would be about 120 amperes, if a 25-volt arc is held on the maximum setting.

The curves of kilovolt-ampere demand, power factor, and regulation apply only

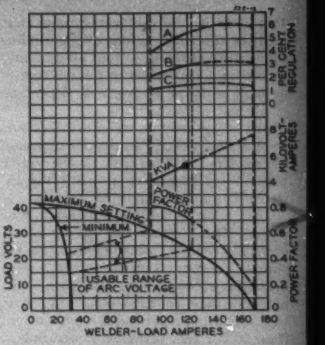


Figure 12. Utility-welder volt-ampere curves with curves of regulation of power source, welder kilovolt-amperes, and power factor when welder is operating at maximum setting

A—Three-kilovolt-ampere distribution transformer

B—Five-kilovolt-ampere distribution transformer

C—42-mile 6,900-volt rural line of 30 miles of number 6 conductor, ten miles of number 8 conductor, and two miles of number 11 conductor

to the maximum setting of the welder; demand and regulation will, of course, decrease at reduced current settings. The line-regulation curve is based on a line likely to be found in rural areas. Power lines in urban areas would have less regulation.

It should be appreciated that the points shown by the curves at zero-load volts occur only momentarily, when the electrode is touched to the work to start the arc.

The maximum 15-minute demand of a welder of this design would not exceed 3.5 kva. A consumer supplied at 230 volts from an individual distribution transformer large enough to handle an electric range would not require additional transformer capacity to supply the welder. This is based on the assumption that the consumer will tolerate light flicker on his premises caused by his own welding load, since he is not likely to operate the welder many hours per year during hours that lights are on. It is not feasible at present to generalize upon regulation problems on systems where several consumers are served from a common distribution secondary circuit because of variation of circuit design used in different localities.

Reference

1. The Service Factor Rating of Arc-Welding Generators and Transformers, R. C. Freeman, A. U. Welch. AIEE Transactions, volume 60, 1941, April section, pages 137–41.

Dodge Chicago Plant's Electric-Power-Distribution Scheme With Airplane-Engine-Testing Power Recovery

E. L. BAILEY
FELLOW AIEE

THE Dodge Chicago plant was built to manufacture airplane engines for superbombers and the entire project was designed exclusively for that one purpose. The plan called for much more than the usual assembly of parts, as it was the intent that this plant make practically everything from castings on through to the finished motor. Accordingly, there are aluminum and magnesium foundries, forge, heat-treat, and machine shops as well as assembly and testing buildings. There are 19 principal buildings with their particular use broadly indicated by their names. The site covers over a square mile.

A list of the equipment in these buildings gives us the connected load, but the use factors for this equipment in each area had to be determined and assigned in order to obtain the power required. Fortunately, when the illumination level and type of lamp were selected for an area, it was straightforward arithmetic to determine the lighting load, as it is considered 100 per cent load factor; but the power demand was much more difficult to determine. The machine shop, our building 4, for example, being the largest one-floor building in the world, covers over 80 acres and contains over 6,000 production machine tools as well as heat-treat, plating, battery charging, conveyors, air-conditioning, building utilities and countless other special features. The estimate for machine demand for all of the buildings is shown in Table I.

At the center of each area of approximately 2,000 kva a double-ended unit substation is placed consisting of two 1,000-kva three-phase 12,000/480-volt transformers and their associated circuit breakers, each feeding a group of radial distribution circuits of approximately 400 to 600 amperes. The 480-volt bus may be paralleled to give service on any circuit in case of emergency by opening one secondary line breaker and closing a tie breaker. The transformers with their associated feeder circuits normally are operated with the tie breaker open, as one approaches very close to the limit of the rupturing capacity on the circuit breakers when the tie breaker is closed. The primary feeds for the two transformers in one substation come from different cables, but there are five transformers on each cable. By this means a dual primary feed on each substation area is obtained, but a separate primary-switch position is not tied up for each transformer. There is some variation from this plan as some locations did not warrant the installation of two transformers, in which case only one was installed with a throw-over primary feed where the operation of the circuit was considered important. The lighting of about 12,000 kw is supplied from the same substations through 50-kva air-cooled transformers (480 volt to 120/240 volt) properly disposed throughout the areas. Combination high-intensity tungsten units are used for the general lighting of about 25 foot-candles, augmented by fluorescent or individual tungsten units for the more critical visual tasks. Fluorescent lamps are used in the offices.

From all these data approximately 90,000-kva connected load was estimated with 39,000-kw probable maximum demand for the plant. However, originally it was provided with only 30,000-kva feed from two 15,000-kva 33-kv circuits in order that it would not be overequipped for power supply. A curve of the estimated load per month was laid out for contact with the public utility company so that it could provide facilities required for the plant as the load grew. It was with some temerity that such a curve was given, but subsequent experience has been gratifying, as there was not too much divergence from it for many months. About a year ago, however, loads indicated that a third 15,000-kva line would be required. It is now installed along with step-type voltage regulators so that now a 45,000-kva power supply is on a firm basis.

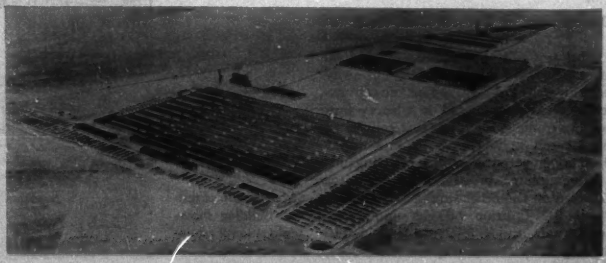


Figure 1. General view of Dodge Chicago plant

Power-Recovery Engine Test

When the production engine-test equipment was being considered, it was immediately evident that the output of these engines, being over 2,200 horsepower, would require very substantial equipment. Further, the amount of power seemed worthwhile salvaging if possible. The engine test requires that the engine be loaded under all conditions of speed and torque that might be expected in flight.

There are at least four commonly accepted plans for loading airplane engines for test. One is simply to install a special propeller or club on to the engine and arrange suitable air-control ducts or tunnels to direct and control the air and noise so that speed–torque curves can be taken. Such a scheme generally is known as a club test. This involves no electric connections other than some scheme for starting the engine and some blowers to carry away the excess fumes and create conditions similar to those in flight surrounding the motor. The actual horsepower developed by an engine while driving a club propeller has to be determined by calibration.

There are three common electrical schemes available; the simplest is what is known as an inductor-type absorption machine, which is simply a short-circuited water-cooled armature mounted in a frame, hung on bearings with a beam scale to measure the torque. This is quite satisfactory and is used by several of the engine builders. The engine has to be cranked for starting by auxiliary equipment as the inductor alternator will not develop torque as a motor.

The second electrical method makes use of an a-c generator connected to the en-

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Figure 2 (left). Typical 2,000-kva 12,000/460 - volt unit substation

Figure 3 (right). Power - absorption generators

gine through some sort of slip coupling, either a fluid or magnetic type. Both of these schemes are used. The results obtained from these hookups also are quite satisfactory. An excellent power factor is maintained on these circuits as the generators are all synchronous type. The power output of the engine is determined by the electric output of the generators plus the generator losses and the slip-coupling losses. This all can be figured out quite simply with the calculated curves of generator losses plus slip-coupling losses and the electric-power measurements. Load can be determined within plus or minus $1^1/_2$ per cent which is quite satisfactory for commercial purposes.

The last scheme for loading the engine is by making use of the variable-speed generators. Here the slip couplings are eliminated. The generator operates over the testing-speed range of the engine output shaft. The calibration of the electric meters may include the generator losses so that direct readings can be taken for use in a simple equation that will give correct engine horsepower output.

In the variable-speed generator the slip losses all are dissipated in an air-cooled resistor so that no problem arises regarding coolant supply.

It seemed that the simplicity of the slip-ring induction generator solidly coupled to the engine without any expensive and troublesome slip coupling would make the most suitable device for loading these high-power-output variable-speed engines. Experience with this type has been most satisfactory from both operating and maintenance point of view.

Description of Typical Test Cell

The test-cell operation is understood most clearly by referring to the cut-away drawing (Figure 4). The newly assembled engine mounted on a heavy supporting frame is run into a test cell shown as test cell 32 where the engine-output shaft is connected by a simple coupling (not a slip coupling) directly to the generator installed on the other side of the cell (see Figure 3). Ignition, oil, gas supply, carburetor, air, and so forth are connected to the engine by means of quick connectors, and the engine is ready to run when the soundproof door of the cell is closed. Since this is an air-cooled engine which exhausts into the cell, exhaust and supply fans are required to produce air movement similar to flight conditions. (These are marked clearly in the drawing.) A forced-air-cooled grid resistor with drum-type control is located on the roof of the building for dissipating the slip losses from the generator secondary circuits.

In using the slip-ring induction generator, the excitation, of course, comes from the supply line. Accordingly, the power factor will not be any better on this generator circuit than that of any normal induction motor of this horsepower and speed, so power-factor correction must be made for the circuit, preferably by a synchronous motor or capacitor, or both, associated with the test stand. By using a 300-horsepower synchronous motor to drive the cooling fan plus 180 kva of static capacitor, it is possible to supply sufficient leading current to give a minimum operating condition of approximately 90 per cent power factor.

Immediately below the generator room is located a switching and transformer room containing also the shunt and series capacitors and various devices for operation of the cell.

Refer to Figure 5 for the sequence of operations for a typical test run as follows:

The remotely controlled air circuit breaker in the test building substation is closed by the test operator from his control booth connecting the slip-ring generator, synchronous-motor-driven supply fan, and a shunt-type static capacitor to the bus of a 2,500-kva 12,000/2,300-volt 60-cycle transformer which, in turn, is connected through a series capacitor to the 12-kv plant system bus.

When the switch is closed, the engine is cranked at low speed, as full secondary or rotor resistance is placed in the circuit, while the supply-fan motor, being thrown across the line, quickly comes up to speed. The shunt-type capacitor helps reduce the current inrush, and together with the synchronous motor, when up to speed and properly excited, brings the

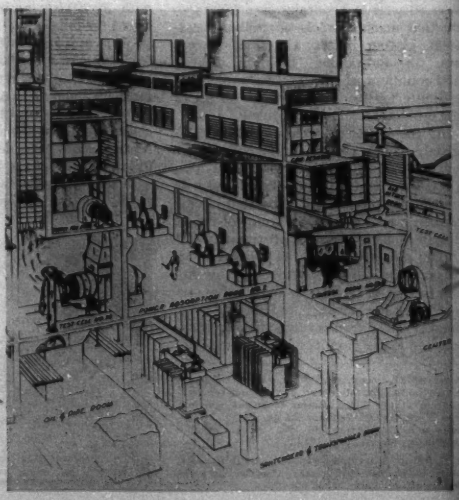

Figure 4. Test-cell building number 5

Cross section of test-cell building showing location of equipment

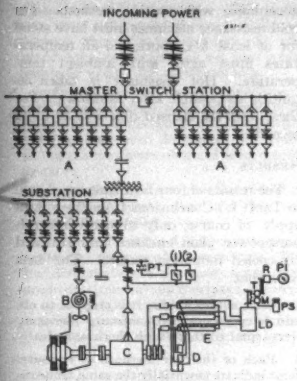

Figure 5. Wiring diagram of test-cell electric elements

1—Kilowatt-hour meter
2—Torque instrument
A—High-voltage feeders
B—Supply fan
C—Induction generator
D—Vernier resistors
E—Leading resistors
R—Receiver
T—Transmitter
LD—Loading drum
M—Drum motor
PS—Position selector
PI—Position indicator
PT—Power transformer

power factor of the group to a satisfactory value for all loads and speeds.

The series capacitor shown in the supply line to the 2,500-kva transformer eliminates the voltage drop due to the reactance loss in the transformer, so that there is no disturbance on the 2,300-volt bus when one of these units is started. This use of a series capacitor is believed to be the first large-scale application of such a device in an industrial plant, and it is gratifying to report trouble-free performance.

After a short period of motoring, to be sure that air and oil are as required, the ignition on the engine is closed, the throttle opened, and the resistor adjusted to give the speeds and loads specified by the engineers for the test. An indicating kilowatt meter connected in the stator circuit indicates the power flow back to the a-c system and also is used to indicate the engine brake horsepower as:

$$\text{Engine brake horsepower} = \frac{(\text{stator power} + \text{stator losses}) \times \text{actual speed}}{\text{synchronous speed}}$$

A factory curve gives losses at all outputs, with conversion factor applied so that a value *K* from the curve times actual speed = brake horsepower.

The power recovery from this system is completely automatic. Engines are started, tested, and removed from the cells with no disturbance of any kind.

Examining the wiring diagram, it will be noted that several test cells are grouped on a 2,300-volt bus. Feeders extend to various plant loads from this bus, including all the cell auxiliaries. This was designed so that the recovery power would operate these associated loads with minimum loss and also reduce the capacity of the transformer that connects to the 12-kv system bus.

Table I. Tabulation of Connected Loads, Load Factors, and Totals for Estimating Plant Demand

Building	Building Name	Connected Power, Kilovolt-Amperes	Load Factor	Maximum Power Demand, Kilovolt-Amperes	Lighting, Kilovolt-Amperes	Maximum Demand, Light and Power
1	Tool shop	500	0.6	300	120	420
2	Office	500	0.5	250	1,200	1,450
3	Personnel	100	0.5	50	100	150
4	Machine shop					
	Machine tools (6,000)	30,000	0.4	12,000	8,500	20,500
	Heat treat	7,500	0.7	5,250		5,250
	Plating	800	0.7	560		560
	Battery charging	760	0.4	300		300
	Maintenance	300	0.4	120		120
	Assembly power	750	0.2	100		150
	High-cycle power	50	0.8	40		40
	Utilities	7,400	1.0	7,400		7,400
	Ventilating fans—roof	4,000	1.0	4,000		4,000
	Ventilating fans—basement	480	1.0	480		480
	Ventilating fans—cafeteria	170	1.0	170	200	370
	Mechanical handling and the like	1,000	1.0	1,000		1,000
6	Oil and chip disposal	700	0.5	350	50	400
7	Aluminum-foundry compressor	3,000	0.4	1,200	900	2,100
		700	1.0	700		700
8	Magnesium-foundry compressor	3,000	0.4	1,200	900	2,100
		500	1.0	500		500
9	Heating plant 1	3,900	0.98	3,800	50	3,850
10	Light forge	1,460	0.6	870	150	1,020
11	Tool and die shop	5,630	0.6	3,400	300	3,700
12	Heavy forge	3,100	0.6	1,860	150	2,010
13	Propeller test	500	1.0	500	30	530
14	Heating plant 2	1,350	0.98	1,300	50	1,350
Miscellaneous outside lighting and power				500	100	600
		78,150		48,200	12,800	61,000

Conclusion

Although the electric power system was designed and installed during the war, it has met adequately the exacting requirements of this large manufacturing project, and the power recovery system for the engine test not only has given us very reliable easily operated trouble-free testing facilities, but also enabled us to supply from an otherwise wasted source over 4,000,000 kilowatt-hours per month or 20 per cent of the electric power required for the project.

Investigation of Hot-Spot Temperatures in Integral-Horsepower Motors

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THE revision of American Standard C50, "Rotating Electrical Machinery," resulted in various suggestions for changing the method of measuring the temperature rise of motors and for establishing temperature-rise limits to be used with these methods. A review of the temperature tests taken in the past indicated that they are of little value for comparing the various methods. Few tests included temperature measurements by more than one method, and none of them had enough embedded detectors to measure accurately the hot-spot temperature. In order to obtain accurate data, the authors were asked to make and report the results of temperature tests on integral-horsepower motors. It was believed that the data thus obtained would be valuable to the standardizing committees of the AIEE, the American Standards Association, and the National Electrical Manufacturers' Association, as well as to motor users.

Scope of Tests

Temperature tests were made on open, plain enclosed (nonventilated), and totally enclosed fan-cooled polyphase integral-horsepower motors. The temperature rise of the stator windings was measured by four methods:

1. Mercury thermometer.
2. Surface thermocouples on the hottest accessible part of the winding.
3. Resistance.
4. Embedded thermocouples (using enough to locate the hot spot).

First Set of Tests*

Description of Motors Tested

In order to obtain a comparison between the temperature rise by thermometer, surface thermocouple resistance, and embedded detector, continuous temperature tests were made on a three-horsepower 1,750 rpm three-phase squirrel-cage induction motor in the 225 frame. One set of readings was taken with the parts assembled as a totally enclosed fan-cooled motor. The other set was taken with the external fan and fan cover removed.

* Data reported by General Electric Company, Lynn, Mass.

Location of Temperature Indicators

A single thermometer for taking coil temperatures was inserted under a felt pad cemented to the outside surface of the end windings on the end opposite the fan. It was impractical to attempt to place a thermometer on the fan end of the motor. A hole was drilled in the end shield to admit the thermometer. The hole was closed around the thermometer with putty. The felt-pad method of mounting the thermometer required more time for preparation than the usual putty method, but the results are considered more reliable.

Thermocouples for taking coil surface temperature were attached to the outside surface of the windings with felt pads and cemented in place. Two thermocouples were used on each end of the winding, one at the top and one at the side; making a total of four.

Thermocouples for taking internal coil temperatures were put in place with the windings. These were located in the center of the slot portion in both top and bottom coils. Five thermocouples were used, two in one slot and one each in three other slots. Two other thermocouples were placed between the slot insulation and the core iron.

Test Procedure

Resistances of the windings were measured with a Kelvin double bridge. Cold and hot resistance were taken in accordance with routine methods. For cold resistance machines must have stood for at least five hours, and all temperatures must agree with ambient temperature. Hot resistance is taken as quickly as possible after shutdown. For these tests the elapsed time was 30 to 40 seconds.

Results

The results of four heat runs are shown in Table I. Conclusions from these data apply, of course, only to small integral-horsepower plain enclosed and enclosed fan-cooled induction motors. The data show that

1. With sufficient care it is possible to obtain temperatures with mercury thermometers equal to those with thermocouples.
2. Each of the four methods of measurement indicate essentially the same temperature.

Any one of them, therefore, may be considered as representing the temperature of the hottest spot within a small margin.

It can be assumed safely that if the highest observed rise by resistance or by one of four thermocouples or one of four carefully installed thermometers is 65 degrees centigrade, then the temperature of the hottest spot is between 65 and 70 degrees centigrade.

Discussion and Conclusions

Conclusions from the three investigations can be applied only to induction motors, since further testing is necessary to establish relationships for d-c machines. From the data already obtained it is evident however, that the relationship between observed surface temperatures and the temperature of the hottest spot for induction motors is quite different from that for d-c motors.

For all classes of machines the point of reference is the temperature of the hottest spot. This temperature, of course, cannot be determined except on a basis of probability, even though one were to take many more temperature readings than are possible on commercial machines. A practical method of measurement, therefore, must be chosen, considering expediency and availability of measuring apparatus. The necessary sacrifice in probable range between the observed temperature and the true hot spot should be consistent with sound economics based on expected useful life of the insulation.

For induction motors in small integral-horsepower sizes of the following, conclusions appear to be sound, based on data from this paper.

(a). *Temperature by Resistance.* Temperature by resistance at the moment of shutdown obtained by extrapolating a cooling curve is very close to the temperature of the hottest spot. The temperature so obtained does not differ greatly from that which would be obtained if a large number of temperature measurements were taken, in-

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This paper, a summary of four conference papers presented at the conference on temperature measurements at the summer technical meeting, St. Louis, Mo., June 26-30, 1944, was prepared by a subcommittee composed of W. R. Hough, F. D. Phillips, and C. P. Potter.

The committee apologizes for having made various changes in the original reports. In order to follow the same form throughout it was necessary to rearrange some of the material, and, in order to conserve paper, it was necessary to omit some of the more detailed information.

cluding embedded detectors. This is for both open and totally enclosed machines, although the difference between the observed temperature and the hot spot is undoubtedly greater for open machines.

Temperature by resistance obtained from a single hot-resistance reading taken within 50 seconds after shutdown is within eight per cent (five degrees at 65 degrees centigrade rise) of the maximum obtained from a cooling curve.

Since cooling curves require more effort to obtain and interpret, their use does not appear to be justified.

The chief advantage of temperature measurement by resistance is its simplicity. The chief disadvantages are necessity for extreme care in determining cold resistance, the need for accurate resistance bridges, and the uncertainty of relying on a single reading which must be taken with extreme care.

(*b*). *Temperature by Thermocouples on End Windings.* Temperature by thermocouples on the end winding is very close to the temperature of the hottest spot. This is true for both open and totally enclosed machines, although the maximum difference between the highest observed temperature and the hottest spot is undoubtedly greater for open machines. Using more thermocouples reduces the average value of this difference so that more margin must be permitted for a single reading than when four or more readings are taken.

The chief advantages of thermocouples for temperature measurement on end windings are:

1. They are easy to install.
2. They can be installed without interfering with the normal ventilation of the machine.
3. They can be installed on coil surfaces not readily accessible to mercury thermometers.
4. Because they are easy to install, a relatively large number of thermocouples can be used with less time required to prepare the machines for the heating test than when using a smaller number of thermometers.

The disadvantage of the thermocouple is that its use requires a thermocouple potentiometer which must be kept in good calibration to be reliable.

(*c*). *Temperature by Mercury Thermometer on End Windings.* Temperature by thermometer on the end windings is the same as that obtained by thermocouple, if special care is used in installing the thermometer and if the size of the machine permits making a good application of the thermometers.

The chief advantage of thermometers for temperature measurement on end windings is that they are readily obtainable. The chief disadvantages of thermometers are:

1. Because of their apparent simplicity, they are likely to be used carelessly.
2. Greater skill is required to obtain accurate readings than is required with thermocouples.
3. Thermometers are difficult to install, because they are not readily accommodated by the mechanical structure.
4. Because they are difficult to install, the tendency is to use too few.

Table I

Phase	Enclosure	Speed, Rpm	Temperature Rise: By Mercury Thermometer, Degrees Centigrade, Actual	By Mercury Thermometer, Per Cent of Hot Spot	By Surface Thermocouple, Degrees Centigrade, Actual	By Surface Thermocouple, Per Cent of Hot Spot	By Resistance, Degrees Centigrade, Actual	By Resistance, Per Cent of Hot Spot	Degrees Centigrade, Hot Spots by Embedded Detector
3	Plain enclosed	1,800	58	98	56	95	61	104	59
3	Plain enclosed	1,800	58	94	57½	93	62	100	62
3	Enclosed fan-cooled	1,800	57	94	64	105	61	100	61
3	Enclosed fan-cooled	1,800	58½	98	62	103	62	103	60

Highest of four thermocouples on outside surface of end windings.

Resistance measured 30 to 40 seconds after shutdown.

Highest of five thermocouples embedded in various places in slot portion of coil.

Table II

Horsepower	Speed	Cycles	Temperature Rise: Laminations, Degrees Centigrade, Actual	Laminations, Per Cent of Hot Spot	Winding by Surface Thermocouple, Degrees Centigrade, Actual	Winding by Surface Thermocouple, Per Cent of Hot Spot	Winding by Resistance, Degrees Centigrade, Actual	Winding by Resistance, Per Cent of Hot Spot	Degrees Centigrade, Hot-Spot by Embedded Detectors
Open Motors									
150	1,200	60	41	89	29	63	31	68	46
60	500	25	39	89	36	82	41	93	44
50	1,000	50	48	89	49	91	43	80	54*
20	500	25	37	88	34	81	35	83	42*
25	1,800	60	37	77	32	67	37	77	48
10	750	25	46	88	46	88	52	100	52
Splashproof Motors									
50	1,800	60	44	79	39	70	43	77	56
25	750	25	56	85	58	88	63	95	66
250	1,800	60	26	87	25	83	26	87	30
250	1,500	50	32	97	29	88	29	88	33
125	750	25	34	90	33	87	32	84	38
Enclosed Motors									
10	1,800	60	69	102	65	95	67	98	68
5	900	30	65	100	64	98	63	97	65
5	750	25	58	94	60	97	58	94	62*
Fan-Cooled Motors									
15	1,800	60	39	71	55	100	53	96	55
15	1,800	60	39	72	53	98	54	100	54
7½	750	25	34	72	48	102	48	98	47
7½	750	25	34	72	48	102	48	98	47
30	600	60	45	75	54	90	53	88	60
25	500	50	47	78	53	88	57	95	60
10	250	25			57	93	58	95	61

* High-slip motors.

Second Set of Tests†

Description of Motors Tested

As wide a variety of motors as possible was selected from motors in current production, and it was possible to obtain open, dripproof, enclosed, and enclosed ventilated motors in a wide range of speeds and horsepowers. All were three-phase squirrel-cage motors, both normal and high torque, normal and high slip; all were insulated before test, and the majority were random-wound, though the larger sizes have form-wound coils insulated before insertion in the slot.

Location of Temperature Indicators

In order to obtain the hot spot, thermocouples were installed in the slots at various points, since it was found, by previous tests, that the hottest spot was located in the slot. Sixteen or more were used and were distributed, four near the bottom of the motor, four near the top, and four at each side, and were located next to the iron, between the two coils, in the coils, and under the wedge. The hottest temperature was obtained between the coils or next to the wedge.

Thermocouples were located in eight places on the coil ends—at the top, bottom, and sides on each end of the motor, and care was taken to install them in the locations giving the highest temperatures. Lamination temperatures were taken in 8 to 12 locations on open or splashproof motors and in two or more locations (through holes bored in the frame) on enclosed motors.

Test Procedure

Temperature rises were measured by surface thermometer (thermocouple), sta-

† Data reported by General Electric Company, Schenectady, N. Y.

Table III

Enclosure	Type of Heat Run	Per Cent Load	Temperature Rise (Running): Winding by Thermometer, Degrees Centigrade, Actual	Winding by Thermometer, Per Cent of Hot Spot	Winding by Surface Thermocouple, Degrees Centigrade, Actual	Winding by Surface Thermocouple, Per Cent of Hot Spot	Winding by Resistance, Degrees Centigrade, Actual	Winding by Resistance, Per Cent of Hot Spot	Degrees Centigrade, Hot Spot by Embedded Detector
Fan cooled	Continuous	75	31.2	89.1	31.6	90.4	32.5	93.0	35.0
Fan cooled	Continuous	100	45.5	90.3	49.4	92.0	53.5	99.6	53.7
Fan cooled	Continuous	125	82.0	89.5	84.4	93.1	88.0	96.0	91.6
Fan cooled	60 minutes	150	89.0	85.6	93.8	90.2	97.5	93.7	104.0
Fan cooled	30 minutes	170	97.0	80.9	104.8	87.3	115.0	95.7	120.0
Plain enclosed	Continuous	75	36.7	92.2	38.1	95.7	40.5	102.0	39.8
Plain enclosed	Continuous	100	57.0	91.0	60.0	95.9	60.5	96.7	62.6
Plain enclosed	Continuous	115	76.0	91.0	77.0	92.3	82.5	98.8	83.5
Plain enclosed	60 minutes	166	50.0	86.6	53.5	92.7	55.5	96.2	57.7
Plain enclosed	30 minutes	250	67.0	85.2	69.5	88.5	73.5	99.8	78.6
Open	Continuous	100	30.5	82.3	33.8	91.1	32.0	86.3	37.1
Open	Continuous	125	51.5	80.9	59.6	93.6	61.5	96.5	63.7
Open	60 minutes	145	60.5	72.2	77.7	92.8	79.5	94.9	83.8
Open	30 minutes	170	62.0	56.6	96.0	87.8	95.8	87.2	109.3

Table IV

Enclosure	Type of Heat Run	Per Cent Load	Temperature Rise (After Shutdown): Winding by Thermometer, Degrees Centigrade, Actual	Winding by Thermometer, Per Cent of Hot Spot	Winding by Surface Thermocouple, Degrees Centigrade, Actual	Winding by Surface Thermocouple, Per Cent of Hot Spot	Winding by Resistance, Degrees Centigrade, Actual	Winding by Resistance, Per Cent of Hot Spot	Degrees Centigrade, Hot Spot by Embedded Detector
Fan cooled	Continuous	75	33.0	94.3	31.6	90.4	32.5	93.0	35.0
Fan cooled	Continuous	100	50.8	94.5	49.5	92.2	53.5	99.6	53.7
Fan cooled	Continuous	125	86.0	93.9	84.4	93.1	88.0	96.0	91.6
Fan cooled	60 minutes	150	96.0	92.2	93.8	90.2	97.5	93.7	104.0
Fan cooled	30 minutes	170	105.5	86.1	109.0	88.9	115.0	93.8	122.5
Plain enclosed	Continuous	75	38.5	95.5	38.1	94.5	40.5	100.5	40.3
Plain enclosed	Continuous	100	59.2	94.5	60.0	95.9	60.5	96.7	62.6
Plain enclosed	Continuous	115	78.5	94.0	77.0	92.3	82.5	98.8	83.5
Plain enclosed	60 minutes	166	54.0	93.6	54.6	94.5	55.5	96.2	57.7
Plain enclosed	30 minutes	250	74.0	90.0	75.8	92.2	78.5	95.5	82.2
Open	Continuous	100	32.5	87.6	33.8	91.1	32.0	86.3	37.1
Open	Continuous	125	58.5	91.8	59.6	93.6	61.5	96.5	63.7
Open	60 minutes	145	73.5	87.3	78.8	94.0	79.5	94.9	83.8
Open	30 minutes	170	94.0	86.0	104.4	95.5	95.5	87.2	109.3

tor-winding resistance, and embedded temperature detector (thermocouple). No mercury thermometers were used, as our practice is to use thermocouples only in obtaining temperatures on heat runs, particularly on enclosed motors, since we have found thermocouples more convenient and easier to install properly than thermometers, as well as easier to read.

Cold resistance and temperature of the motor were carefully measured to obtain the correct base for determining the temperature by resistance. After shutdown, resistance readings were taken as soon as possible and continued for 30 minutes. Cooling curves were plotted for each run and extrapolated to shutdown time to determine temperature rise by resistance. Failure to begin readings quickly and to carry them far enough to determine the slope of the curve would result in large error in the temperature as observed.

The results of the temperature tests are shown in Table II.

Discussion and Conclusions

For open motors the conventional hot-spot allowance for thermometer measurement is given in AIEE Standard 1 as 15 degrees centigrade. The tests recorded in Table II indicate that this allowance is adequate. The same standard gives a conventional hot-spot allowance by resistance measurement of five degrees centigrade. American Standard C-50 gives a limiting temperature rise for general-purpose open motors as 50 degrees centigrade and for other motors as 60 degrees centigrade. Tests indicate that the temperature difference between hot spot and rise by resistance is variable, depending on motor speed and the intensity of ventilation over the coil ends. For open motors it appears that rise by resistance is not a satisfactory method of arriving at hot-spot temperatures.

For enclosed motors and enclosed fan-cooled motors, the conventional hot-spot allowance for thermometer measurements is ten degrees centigrade, and for temperatures by resistance measurements five degrees centigrade. These tests show that coil-end surface temperatures, hot-spot temperatures, and temperatures by resistance measurements are equal within fairly narrow limits. This is due to the fact that intense ventilation of coil ends does not take place in motors of these types. The heat generated is dissipated through the enclosure, and the temperatures of the various internal parts of the motor are quite uniform. The hot-spot allowance of five degrees centigrade between rise by resistance and hot spot is adequate. Because of the convenience of the rise-by-resistance method for motors of these types, this method is strongly recommended for enclosed motors.

Third Set of Tests**

Description of Motors Tested

The motors tested were NEMA frame 254, five horsepower, three phase, four pole, 60 cycle, of fan-cooled, plain enclosed, and open construction; windings in all cases were semienclosed slot, random-wound, with class-A insulation, and untaped coils, varnish impregnated. Temperature tests included continuous 60-minute duty and 30-minute duty for each enclosure. Fan-cooled motors had one outer fan at the end opposite the drive end which forced air across the outer surface of the stator. Plain enclosed motors were of the type having the

** Data reported by Reliance Electric and Engineering Company, Cleveland, Ohio.

Table V

Tests	Enclosure	Time	Temperature Rise: Thermometer, Per Cent of Hot Spot, Running	Thermometer, Per Cent of Hot Spot, Maximum	Thermocouple, Per Cent of Hot Spot, Running	Thermocouple, Per Cent of Hot Spot, Maximum	Resistance, Per Cent of Hot Spot, Running	Resistance, Per Cent of Hot Spot, Maximum
3	Fan cooled	Continuous	89.6	94.2	91.8	91.9	96.2	96.2
3	Plain enclosed	Continuous	91.4	94.6	94.6	94.2	98.5	98.6
2	Open	Continuous	81.6	89.7	92.3	92.3	91.4	91.4
1	Fan cooled	60 minutes	85.6	92.2	90.2	90.2	93.7	93.7
1	Plain enclosed	60 minutes	86.6	93.6	92.7	94.5	96.2	96.2
1	Open	60 minutes	72.2	87.8	92.8	94.0	94.9	94.9
1	Fan cooled	30 minutes	80.9	86.1	87.3	88.9	95.7	93.8
1	Plain enclosed	30 minutes	85.2	90.0	88.5	92.2	99.8	95.5
1	Open	30 minutes	86.6	94.0	87.8	95.5	87.2	87.2

outer surface of the stator core exposed. Open motors were of the double end ventilation construction. The stators were of the dripproof type with air discharge from the lower half of the stator only.

Location of Temperature Indicators

Temperatures of cores and windings were obtained while running, and after shutdown by means of thermometers, surface thermocouples, and embedded thermocouples. The location of thermometers and thermocouples for all motors is shown in Figure 1, reference 1, which represents an axial cross section of the motor in the vertical plane. In addition to the thermocouples shown, the open motor included 14 additional thermocouples. These were spotted in every third coil to determine the temperature distribution circumferentially around the stator.

Test Procedure

The conventional method of measuring resistance of the windings, terminal to terminal, was used following shutdown and included a series of readings which could be plotted against time, and the curve extended to the instant of shutdown. Tests were taken at various percentages of rated load to produce a relatively wide spread in resulting temperature rise.

Results

The pertinent information obtained from these tests is given on Tables III and IV. Both tables give the conditions of test, including enclosure, time, and load. Table III gives maximum temperature rises observed during running and including the instant of shutdown, and, in addition, the temperature rise by resistance as determined within approximately one minute or less after shutdown. The hot-spot temperature rise is the highest observed temperature rise by embedded thermocouple during running. The percentage of the maximum observed rise to the hot-spot rise is given in each case. Table IV differs from Table III only in that the values of maximum temperature rise are those observed either during running or after shutdown, depending on which were higher. Table V is a summary of the average results of like conditions of enclosure and time and includes only the percentage relation to the hot-spot temperature.

Discussion and Conclusions

1. Temperature Rise During Running and After Shutdown

(*a*). There is a substantial difference between temperature rises by thermometer during running and after shutdown. The temperature rises increase after shutdown in practically all cases.

(*b*). There is no significant change in temperature rise by surface thermocouple after shutdown except in the case of intermittent ratings. In the case of 60-minute ratings, the change is minor. In the case of 30-minute ratings, it may be substantial.

(*c*). In all cases the rise by resistance did not increase after the instant of shutdown. The rise by resistance by the conventional method as determined within one minute after shutdown in all cases was within six per cent of the rise at the instant of shutdown. On the average, it was within three per cent.

(*d*). There is no significant change in temperature of the hot spot after shutdown except in the case of intermittent ratings, it may be substantial.

(*c*). In all cases the rise by resistance did not increase after the instant of shutdown. The rise by resistance by the conventional method as determined within one minute after shutdown in all cases was within six per cent of the rise at the instant of shutdown. On the average, it was within three per cent.

(*d*). There is no significant change in temperature of the hot spot after shutdown except in the case of intermittent ratings. In the case of 30-minute

ciently consistent results to be recognized as approved methods.

(*a*). The resistance method most nearly approaches hot-spot temperatures and consequently should be the preferred method.

(*b*). The surface thermocouple next to the resistance method most nearly approaches hot-spot temperatures and should be the next preferred method.

(*c*). The thermometer method should be the least preferred method. If it is used, the maximum rise during running or after shutdown should be the basis of measurement rather than maximum rise during running.

2. The allowable temperature rise in each case should be based on determination as follows:

(*a*). Resistance method—the temperature rise to be determined by resistance measurement within one minute after shutdown.

(*b*). Surface thermocouple—the temperature rise to be determined by the maximum observed reading during running or after shutdown.

(*c*). Thermometer method—the temperature rise to be determined by the maximum observed reading during running or after shutdown.

Fourth Set of Tests‡

Description of Motors Tested

Two 40-horsepower 1,750-rpm three-phase squirrel-cage motors were tested at various loads as reported in AIEE TRANSACTIONS[1] pages 468–72, September 1939. One of these motors was an open motor, and the other was a totally enclosed fan-cooled motor.

Location of Temperature Indicators

In order to be sure of finding the hot spot 40 embedded detectors were installed in the totally enclosed fan-cooled motors, as shown in Figure 1 of reference 1. A mercury thermometer extended through a slot in the end plate and the bulb of the thermometer was immediately adjacent to a surface thermocouple. There were 34 embedded detectors in the open motor, as shown in Figure 2, reference 1, and again the bulb of the mercury thermometer was immediately adjacent to a surface thermocouple. The surface thermocouples and the thermometer bulbs were on the outside of the tape which covers the free ends of the windings and were covered with a small amount of sealing compound. The embedded detectors were located in various parts of the slots and in various parts of the free ends; a complete record of their location may be found in paper referred to.

Test Procedure

Continuous temperature tests were made at various loads, and the temperature readings were taken while the motors were running. A double bridge was used to measure the resistance of the stator winding. At the end of each run the rotor was stopped very quickly, and the stator resistance was measured in a minute or less.

The results of nine heat runs are shown in Table VI.

‡ Data reported by Wagner Electric Corporation, St. Louis, Mo.

Investigation of Hot-Spot Temperatures in Fractional-Horsepower Motors

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THE revision of American Standard *C50*, "Rotating Electrical Machinery," resulted in various suggestions for changing the method of measuring the temperature rise of motors and for establishing temperature-rise limits to be used with these methods. A review of the temperature tests taken in the past indicated that they are of little value for comparing the various methods. Few tests included temperature measurements by more than one method, and none of them had enough embedded detectors to measure accurately the hot-spot temperature. In order to obtain accurate data the authors were asked to make temperature tests on fractional-horsepower motors and to report the results. It was believed that the data thus obtained would be valuable to the standardizing committees of the AIEE, the American Standards Association, and the National Electrical Manufacturers Association, as well as to motor users.

Scope of Tests

Temperature tests were made on open and totally enclosed (nonventilated), single-phase, polyphase, and d-c fractional-horsepower motors, with treated and untreated windings. The temperature rise of the stator windings was measured by four methods:

1. Mercury thermometer.
2. Surface thermocouples on the hottest accessible part of the winding.
3. Resistance.
4. Embedded thermocouples (using enough to locate the hot spot).

First Set of Tests*

Description of Motors Tested

In selecting motors for tests, three types were chosen. They were a one-

* Data reported by Century Electric Company, St. Louis, Mo.

Discussion and Conclusions

While it is possible to obtain fairly accurate measurements of temperature using mercury thermometers in motors which are so constructed that a thermometer can be placed in the right location, it should be borne in mind that many motors have mechanical features which prevent the satisfactory use of mercury thermometers without mutilating the motors. In such cases the temperatures taken are quite likely to be lower than the true values, and the actual operating temperatures of such motors are a good deal higher than the observed readings.

On the other hand, thermocouples are flexible and may readily be placed on the hottest parts of windings so that readings taken using surface thermocouples are more nearly correct than those which are obtained by using mercury thermometers. It is, suggested therefore, that the use of mercury thermometers be discouraged. This might be done by specifying the use of thermocouples and eliminating the use of mercury thermometers, or by specifying a new method which would consist in the determination of temperatures by means of thermocouples applied to the hottest part of the machine accessible to thermocouples.

Summary of Data Reported by All Companies

A brief summary of the preceding data is given in Table VII. In this table, as in the preceding tables, the maximum temperature obtained by embedded detector is considered the hot spot. When temperatures by surface thermocouple or resistance exceed those obtained by means of the embedded detector, either one of two conclusions may be reached; either the embedded detector was not placed in the hottest part of the winding, or an error was made in the measurements.

Reference

1. MEASUREMENT OF TEMPERATURE IN GENERAL-PURPOSE SQUIRREL-CAGE INDUCTION MOTORS, C. P. Potter. AIEE TRANSACTIONS, volume 58, 1939, September section, pages 468–78.

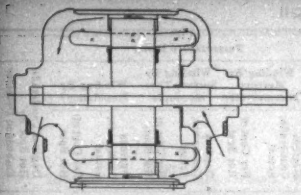

Figure 1. Sectional view showing ventilation and location of thermocouples in Century single-phase motors

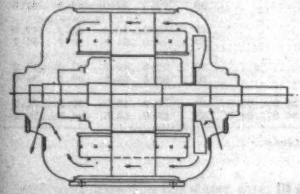

Figure 2. Sectional view showing ventilation and location of thermocouples in Century d-c motors

fourth-horsepower 60-cycle 1,750-rpm single-phase capacitor-start motor, a one-half-horsepower 60-cycle 1,750-rpm, repulsion-start induction-run motor, and a one-half-horsepower, 1,750-rpm d-c compound motor. These motors were tested first as open motors and then as nonventilated enclosed motors. The windings of all motors were given an insulating-varnish treatment before tests were made.

Location of Temperature Indicators

Thermocouples were placed at various positions in the stator coils at the time the coils were put in the slots. Figures 1 and 2 show the location of the thermocouples in the a-c and d-c motors respectively. Thermocouples were placed on the stator-coil extensions as shown. Thermometers were placed as close to the thermocouples on the extensions as practical.

Test Procedure

Each motor was loaded and run until temperatures had become constant. Readings of all thermocouples and thermometers were taken while the motor was running. Resistance readings were taken as soon after shutdown as practical, and the time was recorded. Several more resistance readings were taken over a period of five minutes, and a curve was drawn with ordinates as resistances and abscissas as time. The extension of this curve to zero time gives an approximate value of resistance at the instant of shutdown. This value was used in calculating the temperature rise by resistance shown in the accompanying tables.

Temperatures of the repulsion start and the d-c wound rotors were taken by resistance method and by thermometers after the motor was shutdown. To obtain thermometer readings the motor was rerun and disassembled. The time after shutdown for recording thermometer temperatures was approximately three minutes.

Results

The hot-spot temperatures in both the open-type a-c motors occurred in the winding extension on the air-exhaust end. In the enclosed a-c motors the hot spot occurred at the center of the slot midway between the ends of the core, although the embedded detectors in the coil ends were within a few degrees of the hot spot. In the d-c motor the hot spot occurred in the center of the shunt coil on both the open and enclosed motors.

A comparison of temperatures is shown in Table I, which also presents the relation of thermometer, thermocouple, and resistance values as a percentage of the hot spot. From the table there seems to be a definite relation between temperatures as taken by hot-spot and resistance methods. The average ratio between resistance and hot spot for both the open motors and enclosed motors is 94 per cent. Comparison of temperatures by surface thermocouples and thermometers shows fairly consistent results, but not so close as hot spot and resistance. For thermometer readings the bulbs were placed on the extension close to the thermocouples and readings taken without disturbing the motor assembly. The difference between these two methods probably is caused by the difficulty of holding the thermometer bulb in place due to its size and shape, whereas the thermocouple can be tied in place with little chance of its shifting.

The difference between surface indicators and hot-spot or resistance methods is quite large on the d-c motor. The ratio between hot-spot and resistance temperature was 92 per cent for the open motor and 96 per cent for the enclosed motor. However, the ratio between hot-spot and coil-surface temperatures was 51 per cent for the open motor and 76 per cent for the enclosed motor. This shows that the movement of ventilating air over the field coils plays a great part in reducing the temperature of the coil surface, but a tightly wound coil completely enclosed with heavy wrappings of insulating materials is a very poor radiator for the heat generated within the coil.

Discussion and Conclusions

In general the relation between hot-spot and resistance measurements in open and enclosed fractional-horsepower motors tested is a fixed value.

Measurement of temperatures by resistance is simple and, if done carefully with reliable instruments, is quite accurate. In taking resistance measurements a definite interval of time after shutdown should be established or the results extrapolated back to the time of shutdown.

Table I

Type Motor	Frame Size	Enclosure	Horsepower	Rpm	Temperature Rise: By Mercury Thermometer — Degrees Centigrade, Actual	By Mercury Thermometer — Per Cent of Hot Spot	By Surface Thermocouple — Degrees Centigrade, Actual	By Surface Thermocouple — Per Cent of Hot Spot	By Resistance — Degrees Centigrade, Actual	By Resistance — Per Cent of Hot Spot	Degrees Centigrade Hot Spot by Embedded Detector
Capacitor start—single phase	65	Open	1/4	1,750	43	84	47	92	48	94	51
		Plain enclosed			64	97	65	98.5	62	94	66
Repulsion-start induction-run—single phase	81	Open	1/4	1,750	36	92	37	95	38	97	39
		Plain enclosed			66	90.5	67	92	69	94	73
Direct current	81	Open	1/4	1,750	25	51	25	51	45	92	49
		Plain enclosed			63	76	63	76	80	96	83

Paper 45-32, recommended by the AIEE committee on electric machinery for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted November 17, 1944; made available for printing December 13, 1944.

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This paper, a summary of six conference papers presented at the conference on temperature measurements at the summer technical meeting, St. Louis, Mo., June 26-30, 1944, was prepared by a subcommittee composed of W. R. Hough, F. D. Phillips, and C. P. Potter.

The committee apologizes for having made various changes in the original reports. In order to follow the same form, it was necessary to rearrange some of the material, and, in order to conserve paper, it was necessary to omit some of the more detailed information.

Measuring resistances of wound rotors presents problems, especially in small motors. The inaccessibility makes it difficult to get good contact to the windings and can be a serious source of error. For this reason resistance measurements of wound rotors cannot be relied upon.

The relation between the resistance method and surface temperatures for d-c motors is different from that for the a-c motors tested.

The values for temperature by resistance are the instant of shutdown values and were obtained by plotting the resistance–time curves and extrapolating back to the instant of shutdown. All temperatures were taken while the motor was running.

Second Set of Tests*

Tests were conducted on five standard open-protected motors having four-, six-, and eight-inch stator-punching diameters and rated as follows:

Description of Motors Tested

1/20 horsepower, 115 volts, 60 cycles, single phase, 1,725 rpm, split phase, general purpose.

1/8 horsepower, 115 volts, 60 cycles, single phase, 1,725 rpm, capacitor start, general purpose.

1/4 horsepower, 115 volts, 60 cycles, single phase, 1,725 rpm, split phase, short-hour service.

1/4 horsepower, 220 volts, 60 cycles, three phase, 1,725 rpm, polyphase, general purpose.

1/3 horsepower, 115 volts, 60 cycles, single phase, 1,725 rpm, capacitor start, general purpose.

All of the single-phase motors had the main winding placed in the bottom of the slots with the auxiliary winding on top of it and displaced 90 electrical degrees. The polyphase motor had a symmetrical winding. All windings were treated with a standard grade of commercial varnish. Ventilating openings were located in the lower quadrant of the front and back end shields, beneath the oil reservoirs. The ventilation of the general-purpose motors is shown in Figure 3 and the ventilation of the short-hour-service motor is shown in Figure 4. The centrifugal starting-switch mechanisms were located in the front end of the single-phase motors.

* Data reported by Emerson Electric Manufacturing Company, St. Louis, Mo.

Table II

Open Motors			Temperature Rise: Frame By Thermocouple		Winding By Mercury Thermometer		Winding By Surface Thermocouple		Winding By Resistance*		
Type Motor	Horsepower	Rpm	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade Hot Spot By Embedded Detector
Split phase—general purpose	1/20	1,725	35.1	75.8			40	86.5	43.5	93.9	46.3
			44.0	77.6			50	88.2	53.5	94.3	56.7
Capacitor start—general purpose	1/8	1,725	29.0	66.4			40	91.8	41.7	95.5	43.6
			35.8	65.9			50	92.1	52.0	95.8	54.3
Split phase—short hour service	1/4	1,725	28.0	66.7			40	95.3	40.4	96.3	42.0
			32.5	60.5			50	93.0	51.9	96.7	53.7
Polyphase—general purpose	1/4	1,725	27.7	64.1			40	92.5	40.3	93.4	43.2
			36.3	64.8			50	89.3	53.5	95.5	56.0
Capacitor start—general purpose	1/3	1,725	28.2	63.7	28.5	65.3	40	90.2	43.3	97.7	44.3
			36.0	64.1	36.3	64.6	50	89.0	53.0	94.3	56.2

* Resistance readings taken within one minute of shutdown.

Table III

Plain Enclosed Motors			Temperature Rise: Frame By Thermocouple		Winding By Mercury Thermometer		Winding By Surface Thermocouple		Winding By Resistance*		
Type Motor	Horsepower	Rpm	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade, Actual	Per Cent of Hot Spot	Degrees Centigrade Hot Spot By Embedded Detector
Capacitor start—general purpose	[illegible]	1725	40.9	73.0			55	98.2	54.0	96.4	56.0
			47.8	71.8			65	97.8	64.0	96.3	66.5
Split phase—short hour	1/4	1725	43	73.6			55	98.0	54.6	97.4	56.1
			[illegible]	72.8			65	98.0	65.0	98.0	66.3
Polyphase—general purpose	1/4	1,725	43.2	72.2			55	91.8	59.7	99.7	59.9
			50.2	70.4			65	91.2	70.0	98.3	71.2
Capacitor start—general purpose	1/3	1,725	42.9	75.9	49.0	86.8	55	97.3	56.0	99.2	56.5
			51.2	76.4	57.6	86.0	65	97.1	66.0	98.5	67.0

* Resistance readings taken within one minute of shutdown.

Location of Temperature Indicators

The frame temperatures were obtained from thermocouples placed at approximately the middle of the frame, on the top of the motor. It was possible to obtain the winding temperature by thermometer for the eight-inch stator motor only. The thermometer was placed against the outermost part of the stator winding, at the end of the motor from which the ventilating air was exhausted. The bulb of the thermometer was covered as specified in American Standard C50-1943, paragraph 2.056. The temperatures by surface thermocouples were obtained from thermocouples placed among the outer conductors of the stator winding end wire, at the end of the motor from which the ventilating air was exhausted. The resistance readings that were used in determining the temperature value from differences of resistances were taken using a Wheatstone bridge. For the purpose of determining the hot-spot temperature value, thermocouples were placed at various locations within and around the windings, as these wind-

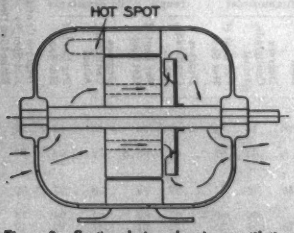

Figure 3. Sectional view showing ventilation in Emerson general-purpose motors

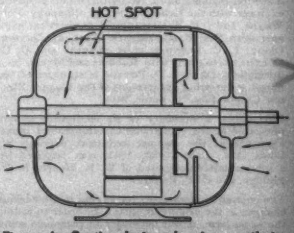

Figure 4. Sectional view showing ventilation in Emerson short-hour-service motors

Table IV

Enclosure	Horsepower	Rpm	Phases	Temperature Rise: By Mercury Thermometer, Degrees Centigrade, Actual	By Mercury Thermometer, Per Cent of Hot Spot	By Surface Thermocouple, Degrees Centigrade, Actual	By Surface Thermocouple, Per Cent of Hot Spot	By Resistance, Degrees Centigrade, Actual	By Resistance, Per Cent of Hot Spot	Degrees Centigrade Hot Spot by Embedded Detector
Plain enclosed and impregnated	1/20	1,725	1	43	75	54	95	53	93	57
	1/4	1,725	1	51	85	60	100	54	90	60
	1/3	1,725	3	52	90	56	97	57	98	58
	3/4	1,725	1	66	92	72	100	68	95	72
Plain enclosed preimpregnated	1/20	1,725	1	43	78	54	98	54	98	55
	1/4	1,725	1	55	82	64	96	66	98	67
	1/3	1,725	3	51	85	57	95	58	97	60
	3/4	1,725	1			76	96	73	93	79
Open and impregnated	1/20	1,725	1	34	79	42	98	41	95	43
	1/3	1,725	1	33	80	38	93	39	95	41
	1/3	1,725	3	40	80	49	98	50	100	50
	3/4	1,725	1	42	79	51	96	47	89	53
Open and preimpregnated	1/20	1,725	1	34	77	43	98	43	98	44
	1/3	1,725	1	34	76	40	89	42	93	45
	1/3	1,725	3	27	79	33	97	32	94	34
	3/4	1,725	1			55	93	55	93	59

ings were placed in the stator core. The highest reading obtained from each test was considered the hot-spot value.

Test Procedure

The motors were tested first as open-protected machines. A set of four or more temperature tests were made at different loads for each motor, so that curves could be drawn to obtain temperature values at desired intermediate load points. Final thermocouple and thermometer readings were taken while the motors were still running, after constant values had been reached. Resistance readings were obtained within one minute after shutdown. Motors in the six- and eight-inch frames then were tested in the same manner as totally enclosed machines. The various temperature indicators were not disturbed when the motors were changed from open-protected to totally enclosed conditions. The internal ventilating fans were retained when the motors were totally enclosed.

Results

As a result of this investigation it was found that in all instances, for open-protected motors, the hottest spot was at the air-exhaust end of the motor at approximately the center of the stator winding, in the end wire about one-half inch outside of the lamination stacking. In all of the motors that were tested, the air entered and left by way of openings in the lower quadrant of the end shields. The highest temperature was always approximately 180 degrees from the center of these openings.

For totally enclosed motors, this location also provided the maximum temperature, though frequently there were other locations equally hot.

Curves were drawn making it possible to determine the load and the frame and thermometer (when taken), resistance-method, and hot-spot temperature rises corresponding with thermocouple temperature rises of both 40 degrees centigrade and 50 degrees centigrade for open-protected motors, and 55 degrees centigrade and 65 degrees centigrade for totally enclosed motors.

These final data are tabulated for open-protected motors in Table II and for totally enclosed motors in Table III.

For the open-protected motors, the values of the thermocouple and resistance temperature rises, as a per cent of the hot-spot value, are as follows:

Thermocouple: Average, 90.8; minimum, 86.5.

Resistance: Average, 95.3; minimum, 93.4.

For totally enclosed motors, the percentage values are as follows:

Thermocouple: Average, 96.3; minimum, 91.2.

Resistance: Average, 98.4; minimum, 96.3.

Discussion and Conclusions

From these tests, it is concluded that it is possible to determine the hot-spot temperature-rise values in fractional-horsepower a-c motors either by means of thermocouple readings as described herein, or by determining the temperature rise from differences of resistances. It is thought that, if the minimum ratio of temperature rises be used, there would exist little probability that the estimated values would not be on the safe side, yet would be sufficiently close to the actual values so as not to provide an overconservative figure.

The resistance method appears to be the more valuable, since the difference between the average and minimum ratios of temperature rises, as given under the heading of "Results," is only about two percentage points. The corresponding ratio based on thermocouple readings is about five per cent.

It is concluded that it is safe, for open-protected motors, to consider a temperature-rise value by thermocouple as representing 85 per cent of the hot-spot value and to consider a temperature-rise value determined from differences of resistances as representing 92 per cent of the hot-spot value.

For totally enclosed motors, it is concluded that it is safe to consider a temperature-rise value by thermocouple as representing 90 per cent of the hot-spot value and to consider a temperature-rise value determined from differences of resistances as representing 95 per cent of the hot-spot value.

Third Set of Tests*

Description of Motors Tested

The motors tested were rated 1/20, 1/4, 1/3, and 3/4 horsepower at 1,725 rpm. The polyphase motors were all one-third horsepower and were approximately the same physical size as the one-fourth-horsepower single-phase motors. The windings of half of the motors were impregnated with an insulating varnish in the conventional manner. The rest of the motors were built with preimpregnated insulation and did not have the conventional varnish impregnation after winding.

Both the open and totally enclosed motors had fans on both ends of the rotor. In the open motors both fans draw air in at the bearing and expel it through openings in the periphery of the end shield. In the totally enclosed motors the fans merely stir up the air. The open motors were protected to such an extent that

* Data reported by General Electric Company, Fort Wayne, Ind.

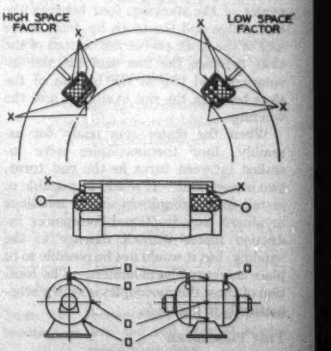

Figure 5. Schematic location of temperature indicators in General Electric motors

□ Mercury thermometers
x Surface thermocouple
O Embedded detectors

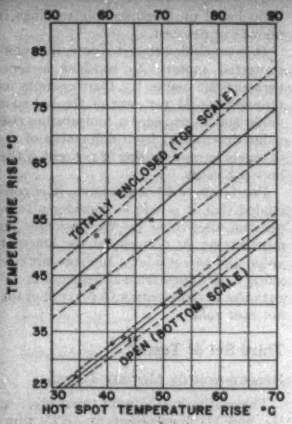

Figure 6. Temperature rise by mercury thermometer of General Electric motors

o Impregnated winding
x Preimpregnated winding

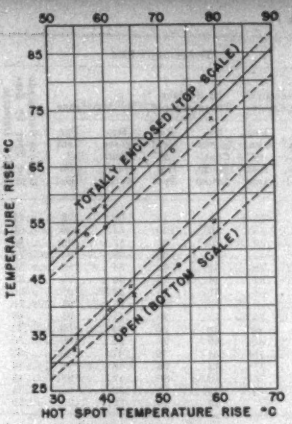

Figure 7. Temperature rise by resistance of General Electric motors

o Impregnated winding
x Preimpregnated winding

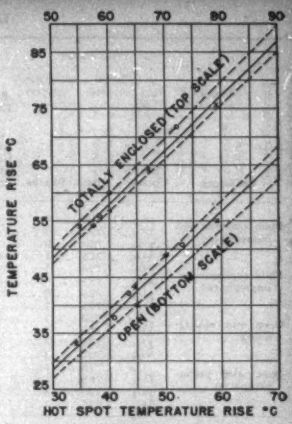

Figure 8. Temperature rise by surface thermocouple of General Electric motors

o Impregnated winding
x Preimpregnated winding

mercury thermometers could not be placed on the windings without disassembly.

Location of Temperature Indicators

Twenty thermocouples were embedded in the winding of each motor in an endeavor to locate the hot spot and determine the magnitude of the temperature gradients in the winding. Four were embedded in the approximate center of the end turns, two on each end. Four were embedded in the center of slots, two in the slot having the highest space factor and two in the slot having the lowest space factor. Twelve were distributed around the periphery of the slots at the center of the stacking, four between the slot wedge and the tooth lip, four at the side of the slots, two at the bottom of the slots between the iron and the slot insulation, and two at the bottom of the slots between the slot insulation and the winding.

When the stator was ready for assembly, four thermocouples were installed between turns in the end turns, two in each end. It would be possible to install thermocouples in similar locations in almost any fractional-horsepower induction motor without damage to the winding, but it would not be possible so to place mercury thermometers. The location of these thermocouples is shown schematically in Figure 5.

Test Procedure

The steady-state temperature rise of the stator windings was measured by four methods: embedded detector, resistance, thermocouple at the hottest spot accessible in the completed stator, and mercury thermometer.

Cold resistance was measured after "soaking" the motors for approximately 12 hours in a closed room. At least six measurements of resistance were made during the first three minutes after shutdown to establish a cooling curve. In almost every test, the first reading was within 30 seconds of shutdown. The cooling curve was plotted on semilogarithmic paper and extrapolated to shutdown time to determine the temperature rise by resistance.

After the first two heat runs, holes were drilled in the motor shells so that two mercury thermometers could be placed permanently on the windings. It normally would not be possible to place mercury thermometers in an equally good position on motors intended for service, but it would be possible on motors selected as representative of a lot.

All tests were taken at an ambient temperature of 25 to 35 degrees centigrade in substantially still air. A dynamometer load was used to obtain approximately 55-degrees-centigrade rise on totally enclosed motors and 40-degrees-centigrade rise on open motors by mercury thermometer.

The maximum temperatures obtained by four methods in 16 heat runs are shown in Table IV.

Discussion and Conclusions

In the following discussion, hot-spot temperature is defined as the highest temperature measured by embedded thermocouple. Analysis of the complete test data indicates that it is very improbable that the true hot spot is significantly higher in the motors covered by this report.

The temperature rise (highest reading) by mercury thermometer, resistance, and end-turn thermocouple is plotted against hot-spot temperature in Figures 6, 7, and 8. The curves, which are straight lines through the origin, show average-, maximum-, and minimum-temperature rise as a function of hot-spot-temperature rise. A wide spread between curves indicates poor co-ordination with true hot-spot temperature; that is, a poor method.

In actual testing, the measured temperature rise is, of course, the independent variable, and the hot-spot temperature which is to be controlled is the dependent variable. Table V shows the range of hot-spot temperatures which would be obtained with certain arbitrarily selected measured temperature-rise limits.

The principal advantages and disadvantages of the three methods used are as follows:

Mercury Thermometer:

Advantages: Equipment availability; established practice.

Disadvantages: Large difference between measurement and hot spot; extreme difficulty in properly placing thermometers in small and in totally enclosed motors.

Table V

	Measured		Range of Hot Spot	
Test Method	Temperature Open, Degrees	Rise Totally Enclosed, Degrees	Temperature Open, Degrees	Rise Totally Enclosed, Degrees
Mercury thermometer	50	55	62–66	60–73
Resistance	60	65	60–68	60–72
Thermocouple	60	65	61–68	65–69

Table VI

Phase	Enclosure	Horsepower	Winding	Temperature Rise By Thermometer: Degrees Centigrade Actual	By Thermometer: Per Cent of Hot Spot	By Thermocouple: Degrees Centigrade Actual	By Thermocouple: Per Cent of Hot Spot	By Resistance: Degrees Centigrade Actual	By Resistance: Per Cent of Hot Spot	Degrees Centigrade Hot Spot by Embedded Detector
3	Dripproof	½	Untreated	39.0	94	39.5	95	40.0	96	41.5
3	Dripproof	½	Treated	38.5	93	39.5	95	40.0	96	41.5
3	Plain enclosed	½	Untreated	59.5	95	60.0	96	62.0	99	62.5
3	Plain enclosed	½	Treated	55.5	94	56.0	95	57.5	97	59.0
3	Enclosed fan-cooled	½	Untreated	48.0	83	49.0	85	52.5	91	58.0
3	Enclosed fan-cooled	½	Treated	39.5	73	48.0	88	53.0	97	54.5
1	Dripproof	½	Untreated	36.0	74	45.5	94	43.4	90	48.5
1	Dripproof	½	Treated	38.0	79	45.0	94	43.5	91	48.0
1	Plain enclosed	½	Untreated	65.0	95	67.0	98	65.5	96	68.5
1	Plain enclosed	½	Treated	59.0	93	61.5	97	60.5	95	63.5
1	Enclosed fan-cooled	½	Untreated	44.0	75	52.5	89	53.5	91	59.0
1	Enclosed fan-cooled	½	Treated	42.0	79	49.5	93	50.0	94	53.5
1	Dripproof	¼	Untreated	40*5	90	43.0	96	42.0	93	45.0
1	Dripproof	¼	Treated	38.0	84	44.0	97	41.5	91	45.5
1	Plain enclosed	¼	Untreated	63.0	91	68.5	98	64.0	92	69.5
1	Plain enclosed	¼	Treated	59.0	88	64.0	96	64.0	96	67.0

Resistance:
Advantages: Equipment availability; usually no disassembly or damage; good co-ordination with hot spot.

Disadvantages: Requires more skill and care, since only one reading is obtained.

Thermocouple:
Advantages: Easy to measure temperature at several places, good co-ordination with hot spot, continuous readings during run.

Disadvantages: Relative scarcity of instruments; disassembly before and after test; same low temperatures as mercury thermometers, if end turns are heavily taped or puttied.

The characteristic which it is desired to control is the hot-spot temperature. It generally is agreed that the hot-spot temperature is not directly measurable on normal commercial machines by simple methods. Since a secondary measurement is necessary, the quantity measured should be related closely to hot-spot temperature so that, first, the user will be protected adequately and, second, the average motor will not have an unnecessarily large size.

According to this criterion, the measurements of temperature rise by resistance and by thermocouple in the end turns are equally good. Both methods measure a temperature considerably closer to hot-spot temperature than mercury thermometers do, and, at least in totally enclosed motors, the measurement is a more consistent indication of hot-spot temperature. Since measurement by resistance and by end-turn thermocouple appear to be equally accurate and, depending on testing conditions, either may be more convenient than the other for a particular motor, both methods should be recognized in the standards. The mercury-thermometer method, which is both less accurate and less convenient, should be discontinued.

In determining the standard temperature rise by any method, the tests showing the most difference between temperature rise by this method and hot-spot temperature rise should be given the most weight. According to this criterion, 65-degrees-centigrade rise by resistance or end-turn thermocouple is equivalent to 55-degrees-centigrade rise by mercury thermometer for totally enclosed motors, and 60-degrees-centigrade rise by resistance or end-turn thermocouple is equivalent to 50-degrees-centigrade rise by mercury thermometer in open motors.

Fourth Set of Tests*

Description of Motors Tested

The test motors were built using all standard parts except the stators. The stators were the standard ones used for dripproof motors of their rating, except that they were wound with a number of thermocouples embedded in the slots and in the end turns. The same stators were used for all tests of a given rating regardless of the effect of the enclosure on the temperature rise at rated load.

Three different four-pole 60-cycle induction motors were tested, a three-fourths-horsepower polyphase squirrel-cage motor, a three-fourths-horsepower single-phase repulsion-start motor, and a one-fourth-horsepower, single-phase repulsion-start motor. Each of the three-fourths-horsepower motors was tested with the following constructions:

1. Dripproof.
2. Totally enclosed nonventilated.
3. Totally enclosed fan-cooled.

The one-fourth-horsepower motor was tested only in the dripproof and totally enclosed nonventilated constructions.

Ventilation of the dripproof motors was obtained by the use of a single fan mounted inside the end shield at the shaft-projection end of the rotor or armature. The totally enclosed nonventilated motors were entirely self-cooled. Motors using totally enclosed, fan-cooled construction were cooled in the conventional manner by a fan mounted on a shaft projection opposite the normal projection. Such motors had no internal fan.

Dripproof end shields were used rather than the old-style open shields, because most present-day fractional-horsepower open motors are practically dripproof motors.

Location of Temperature Indicators

For the determination of the hot spot, thermocouples were placed in the winding when the conductors were being inserted in the slots. The locations of these indicators are shown in Figures 9 and 10. In addition an indicator was placed beneath the slot insulation to allow the measurement of the iron temperature.

It should be noted that it is a simpler problem to locate the hot spot in a polyphase stator than in a single-phase stator, because the heat is generated uniformly in a polyphase stator, whereas the usual single-phase stator has regions of greater and lesser heat generation, depending upon the distribution of the winding.

The hottest accessible spot in the polyphase motor was determined by tests to be between stator coil ends at the end of the winding opposite the shaft projection. In subsequent tests a thermometer was

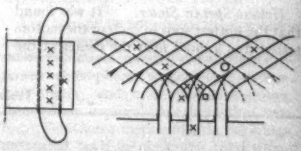

Figure 9. Thermocouple and thermometer locations in slots and coil ends of Master polyphase stator

□ Mercury thermometer
x Surface thermocouples
o Embedded detectors

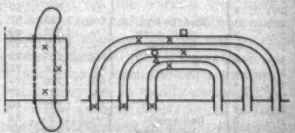

Figure 10. Thermocouple and thermometer locations in slots and coil ends of Master single-phase stator

□ Mercury thermometer
x Surface thermocouples
o Embedded detectors
△ Hottest spot accessible to surface thermocouple

* Data reported by The Master Electric Company, Dayton, Ohio.

inserted here (see Figure 9) and the exposed portion of its bulb covered with modeling clay as recommended in AIEE Standard 9. A thermocouple was tied in place as close to the thermometer bulb as was possible.

The construction of the single-phase motors was such that the thermometer (see Figure 10) had to be placed on the outside of the coil-end extension. In this type of motor a much more desirable place was available for the location of a thermocouple, namely in the interstice formed where the coils were tied on the ends. A surface thermocouple was placed at this point.

Test Procedure

Motors were loaded until the temperature rises were approximately 40 degrees centigrade for the dripproof construction and 55 degrees centigrade for the totally enclosed constructions. Each test was continued until all temperature indicators remained constant for at least four consecutive readings spaced 15 minutes apart. After shutdown the resistance of the stator was measured several times in a period of approximately five minutes to permit extrapolation of the time–resistance curve back to the time of shutdown.

The same stator and temperature indicators were used for all tests of a given rating and were in exactly the same locations.

Results of these tests are shown in Table VI.

Discussion and Conclusions

Hottest Spot in Stator. It was found that the hottest spot in each of the motors tested was located near the center of the end turns, at the top of the winding opposite the shaft-projection end of the stator. In the case of totally enclosed motors there were often several spots at the maximum temperature, but the location just described was always one of these.

Hottest Normally Accessible Spot in Stator. An examination of the data for the three-fourths-horsepower polyphase motor shown in Table VI indicates that when thermometers and thermocouples are placed identically there is relatively little difference between their indications. In cases where construction is such that the thermometer can have only a limited contact with the winding, the use of properly placed thermocouples gives a definite advantage because of the ease with which a surface-thermocouple may be inserted in a desirable location.

All of the data shown herein indicate that the hottest accessible spot in an induction-motor stator which is ventilated by a single internal fan is at an interstice in the coil-end connections at the end opposite the fan.

Temperature Rise as Indicated by Change in Stator Resistance. The temperature rise calculated from the change in stator resistance can be seen to provide a dependable means for determining the temperature rise of stators.

For greatest accuracy the resistance should be measured at suitable intervals up to about five minutes after shutdown, the curve of resistance versus time after shutdown plotted, the curve extrapolated back to zero time, or time of shutdown, and the stator resistance at this time determined. This curve may be plotted on ordinary co-ordinate paper. Usually it will be almost linear, unless the final temperature reading is less than 85 per cent of the shutdown value.

In general for fractional-horsepower motors there is less than one per cent error in the resistance value, if it has been measured in less than one minute after shutdown.

Comparison of Results. Examination of the data shows that for plain totally enclosed motors all three of the methods of temperature measurement used provide consistent results which do not differ greatly from the hot-spot temperature. The data also indicate that for dripproof and totally enclosed fan-cooled motors the thermometer method is considerably less consistent than either of the other two methods.

Fifth Set of Tests

Descriptions of Motors Tested

Tests were made on fractional-horsepower motors employing laminations in common use. These had four flats forming four open sectors between core and shell. Other designs used completely round laminations with better opportunity for heat conduction from laminations to outer shell. Ventilation with such construction was by fans at both ends.

In all cases the slots were insulated by 0.010-inch insulating paper. Formvar or enamel-insulated wires were used, and the windings were not varnish treated.

No attempt was made to use windings representing commercially acceptable temperature rises. The enclosed motors were not intended for such service and in some cases the load was reduced to prevent excessive final temperatures.

Past experience indicated that the fans used with this line of motors differed in their effects with direction of rotation. For that reason many of the tests were repeated with reversed rotation, forming a convenient check on results.

Location of Temperature Indicators

Approximately 64 thermocouples were used with a potentiometer. Embedded thermocouples were placed in the centers of all coils and on the centerline of the field cores at the time of winding insertion. Thermocouples on the surfaces of the end coils were held in place by fuller's earth and sodium silicate.

Test Procedure

Although it would be a comparatively simple matter to arrange a series of heat runs, measuring the rise by various methods, such a procedure still could leave unanswered several questions which might possibly have affected the results. For this reason, possible influential factors were listed and a series of tests arranged

Table VII

Core Length, Feet	Coils	Ventilation	Horsepower	Rpm	Temperature Rise: By Mercury Thermometer, Degrees Centigrade, Actual	By Mercury Thermometer, Per Cent of Hot Spot	Surface Thermocouple, Degrees Centigrade, Actual	Surface Thermocouple, Per Cent of Hot Spot	By Resistance, Degrees Centigrade, Actual	By Resistance, Per Cent of Hot Spot	Degrees Centigrade Hot Spot by Embedded Detector
2⅜	4	End to end, open both rotations	½	1,725	42	85.5	49	100	50.5	103	49
2⅜	4		¼	1,725	42.5	87	48	98	47.5	97	49
2⅜	3		½	1,725	37	71.2	48	92	47.3	91	52
2⅜	3		¼	1,725	40	74	50	92.5	49.8	92.5	54
1½	3		½	1,725	27	93	29	100	26.5	91.5	29
1½	3		¼	1,725	25	86.4	28	96.5	28.5	98.3	29
1½	4		½	1,725	25	86.4	28	96.5	28.8	99.4	29
1½	4		¼	1,725	24	82.7	27	93	27.5	94.9	29
2⅜	4	End-ventilated, open both rotations	½	1,725	37	90	42	102	40.5	99	41
2⅜	4		¼	1,725	40	89	45	100	45	100	45
2⅜	3		½	1,725	38	90.5	43	102	39.5	94	42
2⅜	3		¼	1,725	37	88	42	100	39.4	94	42
2	3		½	1,725	41	91.1	44	98	39.5	87.7	45
2	3		¼	1,725	39	97.5	39	97.5	40.5	101	40
2	4		½	1,725	40	93	41	95	40.7	94.8	43
2	4		¼	1,725	40	91	42	95.5	43.5	98.8	44
2⅜	4	Plain enclosed	½	1,725	71	91	79	101	76.5	98	78
2⅜	3		¼	1,725	69	85.4	78	96	76.5	94.5	81
1⅜	3		½	1,725	67	90.7	73	99	71.5	96.7	74
2⅜	4		¼	1,725	57	87.8	65	100	68.8	105.7	65
2⅜	3		½	1,725	60	90	68	101	67.5	101	67
2	3		¼	1,725	62	85	72	99	65.2	89.4	73
2	4		½	1,725	62	90	67	97	65.5	95	69
1⅜	4		¼	1,725	60	82.3	71	97	68.8	94.2	73

*Data reported by Robbins and Myers, Inc., Springfield, Ohio.

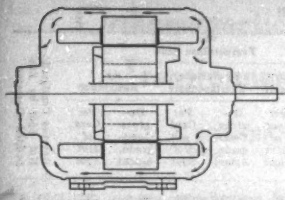

Figure 11. Sectional view showing ventilation of Wagner one-sixth-horsepower single-phase and polyphase motors

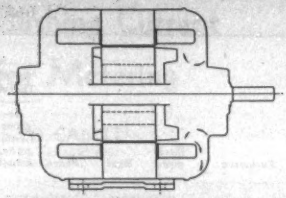

Figure 12. Sectional view showing ventilation of Wagner one-half-horsepower polyphase motors

so that the effect of these factors might be shown up, if present.

The amount of cooling air and the manner in which it is passed over and about the cores and windings are of importance in determining the final temperature rise of open motors. However, practical considerations limit air-delivery and heat-dissipation facilities. Within such limits it would appear that the general *pattern* of temperatures throughout an open motor would be unaffected by the amount of cooling air. For this reason changes in fans and amounts of cooling air were not planned as factors in these tests. In the fully enclosed motor, heat-transfer and dissipating facilities influence the final temperatures. However, the general pattern of temperatures throughout a closed motor was believed to remain unchanged by such features.

Tests investigating possible ventilation effects, therefore, neglected the above factors and considered instead only the following conditions:

1. Open motors: end-to-end ventilation; end ventilation.

2. Closed motors: no special heat-dissipating methods employed.

The ratio of slot area to slot length might influence temperature gradient and hot-spot values. Or in other words, it is conceivable that a change in core length, for the same laminations, might result in a similar change in hot-spot and end-coil temperature differentials. To investigate this possible effect, tests were made with motors having different lengths of core.

In designing single-phase motors, the extent of the distribution of the concentric stator coils frequently affects the final temperature rise. Some designs show a reduced rise through distributing the field in more slots. The possible effect of this distribution of coils and heat on hot-spot temperatures was investigated by repeating tests with three coils per pole and four coils per pole in the stator winding.

It was assumed at the outset of these tests that, even if the possible items listed previously should prove to be of no influence on the final pattern of temperatures, the repetitive nature of the tests would prove of value as a check on results. These items formed the key shown on the test sheets by which individual heat runs can be identified.

The motor under test was clamped to a metal bedplate on the dynamometer stand. Some heat flow to the bedplate resulted, but it was thought unnecessary to attempt to eliminate or minimize this effect.

Results of these tests are shown in Table VII.

Discussion and Recommendations

One disconcerting result noted at once in the tabulation, is the tendency for resistance measurements to indicate temperatures higher than the hot-spot values. (Percentage greater than 100.) Since resistance measurements presumably represent an average, this shows an average greater than its highest component. There are three possible explanations:

1. The true hot-spot was higher than that read. Had only a few thermocouples been used, it would be likely that such a spot could be missed. Under the circumstances it seems unlikely.

2. The rotor was considerably hotter than the stator copper, and immediately on shutdown the stator copper increased in temperature by reflected heat. Such a phenomenon is frequently observed. Such an explanation would not hold here as the repeat test with opposite rotation then should have shown the same effect with the ratio also over 100 per cent. It will be noted that this never occurred.

3. The third, inescapable conclusion is that all temperatures by resistance showing this ratio greater than 100 per cent represent incorrect and, hence, useless readings.

This point is mentioned because it shows up one defect in the rise-by-resistance method. The writers and the organization with which they are connected have used resistance measurements for years as an indication of temperature rise. It has been used in those cases where it:

1. Is the only practicable method.

2. Forms a useful check on other measurements.

To the writers it appears to be a one-shot method, with little chance for a check on human or instrumental error. The possible improvement by taking a series of resistance measurements, after shutdown at accurately determined intervals, does not appear to overcome the difficulties, because such points may rise or fall with time, depending upon reflected rotor heat. Hence extrapolation of points to determine exact shutdown temperature appears as a dubious improvement.

A few statements might be of interest:

1. The hottest spot measured by any embedded detector was never more than four degrees from that measured on the end coils of the same motor by thermocouples. Generally they were only one or two degrees apart.

2. The general pattern of temperatures for the various motors was very similar for end thermocouples versus embedded detectors versus hot spots. In contrast, thermometer readings displayed the greatest range.

3. Reduced stack did not result in a more uniform pattern of temperature with lower hot-spot increase. It must be remembered, however, that any one stack was provided with other variable elements, such as numbers of coils and changes in ventilation method.

4. It would appear that the introduction of cooling air into one end of the motor only, results in hot spots considerably higher than the average temperature. Ventilating both ends of the motor gives more uniform temperature rises.

Sixth Set of Tests*

Description of Motors Tested

The ratings tested consisted of a one-sixth-horsepower single-phase capacitor-start induction motor, one-sixth-horsepower three-phase, squirrel-cage induction motor, and a one-half-horsepower three-phase, squirrel-cage induction motor. Tests were made with the windings untreated both as open and totally enclosed motors. The windings then were treated with insulating varnish, and the tests were repeated both as open and totally enclosed motors. The reason for making tests with the stator windings both treated and untreated was to determine whether the temperature rise might be affected by the varnish treatment. The reason for making tests both as open and totally enclosed motors was to determine whether the temperatures in various parts of open motors are as uniform as they are in totally enclosed motors. The general construction of the one-sixth-horsepower motors is shown in Figure 11. It will be noted that the one-sixth-horsepower motors have ventilating spaces between the stator core iron and the frame, and the rotor is of cast aluminum construction with blower blades on only one end. The construction of the one-half-horsepower motor is shown in

* Data reported by Wagner Electric Corporation, St. Louis, Mo.

Figure 12. It will be noted that it does not have ventilating spaces between the frame and the core but that the rotor is of cast aluminum with blower blades on only one end.

Location of Temperature Indicators

Sixteen thermocouples were placed in each of these motors in various slots midway between the two ends of the core stack and distributed uniformly around the circumference. Some of these thermocouples were damaged during the winding operating, and, therefore, all of them could not be used. The minimum number of thermocouples which were used in any of the motors is nine in the one-sixth-horsepower single-phase motor. It is believed that enough thermocouples were used in all of the motors to obtain a fair approximation of the hot-spot temperature. Surface thermocouples were placed on the hottest accessible part of the free ends of the winding, and mercury thermometers also were placed in the hottest places which were accessible to the thermometers.

Test Procedure

Continuous temperature tests were made on all three motors both open and totally enclosed with the windings treated and untreated. Particular care was taken to obtain accurate resistance readings, and the cold-resistance readings were taken after the motors had remained in a room of practically constant temperature for a period of several hours. Hot resistances were taken within ten seconds after shutdown. This was done by using three more so as to obtain the hot resistance in the shortest possible time. The temperature readings were taken on the thermometers and thermocouples while the motor was operating and were not continued after shutdown. The same stator thermocouples and embedded detectors were used for all four tests on a given rating.

The results are summarized in Table VIII.

Discussion and Conclusions

Although it is possible to obtain fairly accurate measurements of temperatures, using mercury thermometers, in motors which are so constructed that a thermometer can be placed in the right location, it should be borne in mind that many motors have mechanical features which prevent the satisfactory use of mercury thermometers without mutilating the motors. In such cases the temperatures taken are quite likely to be lower than the true values, and the actual operating temperatures of such motors are a good deal higher than the observed readings.

On the other hand, thermocouples are flexible and may be placed readily on the hottest parts of windings so that readings taken using surface thermocouples are more nearly correct than those which are obtained by using mercury thermometers. It is, therefore, suggested that the use of mercury thermometers be discouraged. This might be done by specifying the use of thermocouples and eliminating the use of mercury thermometers, or by specifying a new method which would consist in the determination of temperatures by means of thermocouples applied to the hottest part of the machine accessible to thermocouples.

Table VIII

Enclosure	Horsepower	Rpm	Phase	Temperature Rise: By Mercury Thermometer, Degrees Centigrade, Actual	By Mercury Thermometer, Per Cent of Hot Spot	By Surface Thermocouple, Degrees Centigrade, Actual	By Surface Thermocouple, Per Cent of Hot Spot	By Resistance, Degrees Centigrade, Actual	By Resistance, Per Cent of Hot Spot	Degrees Centigrade Hot Spot by Embedded Detector
Open untreated	1/2	1,750	3	37.7	70	53.0	98	49.9	92	54.1
	1/4	1,750	3			43.2	92	44.1	94	47.1
	1/4	1,750	1	40.0	75	45.8	86	50.8	95	53.3
Open treated	1/2	1,750	3	37.4	78	48.8	102	47.3	99	48.0
	1/4	1,750	3	35.7	89	38.6	96	39.0	97	40.0
	1/4	1,750	1	35.1	79	37.7	84	43.5	97	44.6
Plain enclosed untreated	1/2	1,750	3	42.7	82	52.6	100	48.8	93	52.3
	1/4	1,740	3	48.6	90	48.3	89	52.7	98	54
	1/4	1,750	1	49.1	85	52.8	91	54.3	94	58.0
Plain enclosed treated	1/2	1,750	3	45.4	83	56.0	102	52.0	95	54.8
	1/4	1,750	3	50.2	96	50.2	96	52.0	100	52.2
	1/4	1,750	1	46.2	90	47.4	92	50.8	99	51.5

Table IX. Summary of Tests on Fractional-Horsepower A-C Motors

Manufacturer	Enclosure	Temperature Rise: Thermometer, Per Cent of Hot Spot	Surface Thermocouple, Per Cent of Hot Spot	Resistance, Per Cent of Hot Spot
Century	Open	84–92	92–95	94–97
Emerson	Open	61–78*	87–95	93–98
General Electric	Open	76–80	89–98	89–100
Master	Open	74–94	94–97	90–96
Robbins and Myers	Open	71–93	93–102	88–103
Wagner	Open	70–89	84–102	92–99
All tests	Open	61–98	84–102	88–103
Century	Plain enclosed	91–97	92–99	94–94
Emerson	Plain enclosed	70–76*	91–98	96–100
General Electric	Plain enclosed	75–92	95–100	90–98
Master	Plain enclosed	88–95	95–98	92–99
Robbins and Myers	Plain enclosed	82–91	96–101	89–106
Wagner	Plain enclosed	82–96	89–102	93–100
All tests	Plain enclosed	70–97	89–102	89–106
Master	Enclosed fan-cooled	73–83	85–93	91–97

* Frame temperature.

Summary of Data Reported by All Companies

A brief summary of the preceding data is given in Table IX. In this table, as in the preceding tables, the maximum temperature obtained by embedded detector is considered the hot spot. When temperatures by surface thermocouple or resistance exceed those obtained by means of the embedded detector, either one of two conclusions may be reached: either the embedded detector was not placed in the hottest part of the winding, or an error was made in the measurements.

Orthomagnetic Bushing Current Transformer for Metering

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FELLOW AIEE

BUSHING current transformers are ideal for many reasons. They are compact, convenient, economical, and, from the operator's standpoint, they eliminate a separate piece of equipment. But they have one inherent limitation, namely, an accuracy generally not satisfactory for metering. Many efforts therefore have been made in the past to overcome this inherent limitation of the conventional design, with considerable success in the laboratory but limited success in practice.

The factor that causes inaccuracy in current transformers is a minute nuisance burden (1–10 volt-ampere excitation loss) consumed in the core. The bushing-type current transformer is handicapped particularly in this matter because its exciting ampere turns are necessarily very few, the primary winding consisting of but a single turn, a through conductor, and, therefore, for a given instrument burden into which a given current is to be transformed, the volts per turn, the flux density, and the volt-amperes consumed by the core have to be correspondingly higher. It may well surprise one that in all these years some way has not been found to deliver these few volt-amperes from the powerhouse by some means that will relieve the primary from this nuisance burden. A significant step now has been taken in this direction. The device is called orthomagnetic for reasons explained below.

Principle

If a core is excited from an a-c source and then a higher-frequency excitation superimposed on it through a separate winding of suitable design, maintaining the original excitation unchanged, it will be observed that the volt-ampere input by the original (lower-frequency) circuit is diminished by the superposition, although the total losses in the core may be considerably increased. That is, the higher-frequency source furnishes more than what might be considered its proper share of the total volt-amperes consumed by the core; the lower-frequency source, less than its share. Thus, toward the lower-frequency source, the iron behaves as an improved material; toward the higher-frequency source, as a degraded material. That this cannot be a matter of one circuit delivering power to the other circuit in the ordinary way will be appreciated by remembering the mathematical law that voltage at one frequency cannot produce power with current of another frequency. In fact, in the practical application of the principle under discussion, the two circuits are designed with their mutual inductances balanced out (Figure 1), so that the higher-frequency circuit cannot induce any current in the lower-frequency circuit, and vice versa. It will be seen in Figure 1 that the connections of coil $b2$ are reversed, making the mutual induction between coils a_2 and b_2 opposite to that between a_1 and b_1, and therefore the mutual induction between circuits A and B will be zero. With only ordinary care used in making the two cores and windings alike in the current transformers here reported, no appreciable current of higher-frequency could be detected in the lower-frequency (primary and secondary) circuits (Figure 6).

Some understanding of the rationale of the phenomenon perhaps may be gained from the following elementary discussion.

Referring to Figure 2, let a-b-c-d-e represent the hysteresis loop corresponding to the 60-cycle excitation in the absence of any other excitation. If the state of affairs at the point a is considered, it is seen that the magnetizing current is zero, and there is a residual magnetism a-a'. If, now, a high-frequency excitation is superimposed on the core (the higher the frequency the better for this explanation), this residual magnetism will be eliminated after several cycles of the high-frequency excitation, and a will move up to a': that is, while the low-frequency current is still the same, the flux density corresponding to it will be changed.

If the low-frequency ampere-turns are equal to the abscissa of b, then normally, in the absence of any other excitation, the flux density will be the ordinate of b, representing a residual magnetism b-b', where b' is some intermediate value between the ordinates of the ascending and the descending portions of the loop for the given abscisssa. If, now, a high-frequency excitation is superimposed, this residual magnetism is eliminated, and b moves up to b'.

Similarly to the foregoing, under the residual demagnetizing action of the high-frequency excitation, c moves to c', and so forth, and thus the low-frequency magnetization moves along a', b', c', d, c', b', a', and so on, instead of a, b, c, d, e. Thus, theoretically, the low-frequency hysteresis loss can be eliminated with the aid of simultaneous high-frequency excitation. The low-frequency eddy-current loss, however, cannot be affected materially by the high-frequency excitation.

That the hysteresis loss associated with a d-c loop is reduced, if simultaneously an a-c excitation is superimposed, seems to have been observed first by Gerosa and Finzi in Italy more than half a century ago.[1] Later investigators observed that, if two a-c excitations are applied simultaneously, the higher frequency excitation tends to furnish a larger fraction of the hysteresis loss.[2] In the late '20's the present authors discovered or redis-

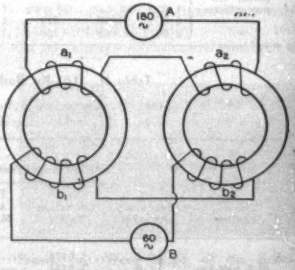

Figure 1. Diagram of connection to study the excitation characteristics of magnetic cores simultaneously excited at two different frequencies

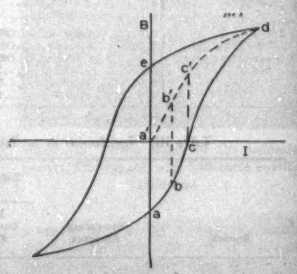

Figure 2. Performance of the auxiliary high-frequency excitation in reducing the residual flux due to the lower-frequency excitation

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covered that not only the hysteresis loss but also the reactive volt-amperes can be reduced in this way, and they proposed to utilize this principle to reduce the exciting current and thereby improve the accuracy of the bushing-type current transformer.[3] Outwardly the device was somewhat similar to the one here reported, but it could not be reduced to commercial practice for several reasons. First, the frequency of the auxiliary excitation would have to be about seven times that of the circuit to be metered, and so, since there was no commercially feasible means of securing such frequency, the idea could not be exploited commercially. Second, even if this frequency were provided, only borderline cases could be improved to good accuracy by this means, because the reduction would be fractional at best, and the scope of the application of the principle would be very limited.

The new factor in the situation which makes the auxiliary higher-frequency excitation a success where it had failed before is the discovery that the volt-ampere characteristic curve can be linearized by proper choice of auxiliary excitation, that the benefits derived from this principle may be many times those from a mere reduction of either the watt losses or of the exciting current, and that, if advantage is taken of this fact, triple-frequency instead of sevenfold frequency auxiliary excitation may be used.

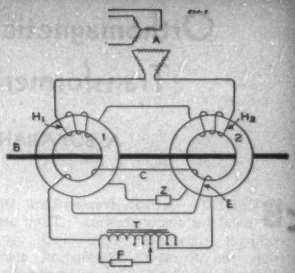


Figure 3. Diagram of connection of a bushing-type current transformer with auxiliary triple-frequency excitation

A = triple-frequency transformers
B = primary conductor
1 and 2 = cores
H_1 and H_2 = winding for the triple-frequency excitation
C = auxiliary winding
Z = compensating burden
E = main secondary winding
T = autotransformer
F = burden

A device incorporating a core of which the magnetization has been rendered straight, by auxiliary higher-frequency excitation, has been christened by the authors orthomagnetic (having straight-line magnetic characteristics).

Table I. 69-Kv Current Transformer

100:5 Amperes (20 Secondary Turns), Two Cores, Each 10⅜ Inches Inside Diameter by 12⅝ Inches Outside Diameter by 5¼ Inches High, Total Core Weight = 100 Pounds

		Plain Current Transformer		Triple Frequency Excitation Added		Impeder (Z) Added		Complete With Autotransformer	
Burden	Secondary Amperes	Ratio Correction Factor	Phase Angle, Minutes	Ratio Correction Factor	Phase Angle, Minutes	Ratio Correction Factor	Phase Angle, Minutes	Ratio Correction Factor	Phase Angle, Minutes
Y (15 volt-amperes, 0.9 power factor)	0.5	Off scale	Off scale	1.0215	+25	1.0184	+3	1.0005	+5
	1.0	Off scale	Off scale	1.0216	+26	1.0184	+3	1.0004	+4
	3.0	1.082	216	1.0211	+21	1.0180	−1	1.0003	+1
	5.0	1.068	156	1.0212	+16	1.0180	−5	1.0004	−2

Table II. 161-Kv Bushing-Type Current Transformer

Ratio 150/5 Amperes (30 Secondary Turns), Two Cores, Each 20 Inches Inside Diameter by 24¾ Inches Outside Diameter by 2 Inches High

		Plain Current Transformer		High-Frequency Excitation Added		With Impeder and Autotransformer	
Burden	Secondary Amperes	Ratio Correction Factor	Phase Angle, Minutes	Ratio Correction Factor	Phase Angle, Minutes	Ratio Correction Factor	Phase Angle, Minutes
X (2.5 volt-amperes, 0.9 power factor)	0.5	1.0174	103	1.0022	3		
	1.0	1.0154	81	1.0027	4		
	2.0	1.0138	64	1.0028	4		
	3.0	1.0130	59	1.0031	4		
	5.0	1.0119	43	1.0033	5		
Y (15 volt-amperes, 0.9 power factor)	0.5	1.0665	263	1.0149	12	1.0056	+4
	1.0	1.0591	196	1.0156	13	1.0050	+3
	2.0	1.0510	134	1.0157	13	1.0047	+3
	3.0	1.0463	103	1.0158	13	1.0045	+1
	5.0	1.0400	72	1.0158	13	1.0043	0
Z (50 volt-amperes, 1.0 power factor)	0.5	Off scale	Off scale	1.0443	125	1.0020	+18
	1.0	Off scale	Off scale	1.0439	120	1.0014	+10
	2.0	Off scale	Off scale	1.0433	106	1.0006	+2
	3.0	1.086	350	1.0433	100	1.0012	−4
	4.0	1.081	300	1.0440	100	1.0018	−7
	5.0	1.077	250	1.0443	100	1.0019	−14

Table III. Transformer as in Table II But Wound for 300/5 Amperes

		High-Frequency Excitation Added		With Impeder and Autotransformer	
Burden	Secondary Amperes	Ratio Correction Factor	Phase Angle, Minutes	Ratio Correction Factor	Phase Angle, Minutes
Y (15 volt-ampere, 0.9 power factor)	0.5	1.0046	+3	1.0003	+3
	1	1.0048	+2	1.0002	+2
	3	1.0043	+2	1.0000	+2
	5	1.0041	−1	0.9998	−1

Current-Transformer Circuit

In Figure 3, *B* is the through conductor of a bushing and constitutes the primary winding; 1 and 2 are duplicate wound-strip cores; *E* is the secondary winding; H_1-H_2, the 180-cycle excitation winding; *T*, an autotransformer inserted between the secondary winding and the burden, with a number of small tap-steps to make precise adjustment of the current ratio; *Z*, a phase-angle compensating impeder; and *F*, the burden.

The need for the autotransformer will be appreciated, if it be remembered that the primary being only one turn and the secondary 10–50 turns, one secondary turn may represent a two–ten per cent step which would not be fine enough. The autotransformer and the impeder are a separate piece of equipment from the current transformer and may be mounted apart from it.

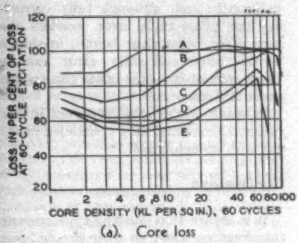
The equipment to furnish the 180-cycle excitation to the current transformer is shown in Figures 3 and 7, consisting of a wye-delta bank of three small single-phase transformers, with the corner of the delta opened for connection to the terminals of winding H_1-H_2 as a single-phase system, while the wye-winding is excited from a three-phase 60-cycle source.

As the theory of static third-harmonic generators (also called frequency-multi-

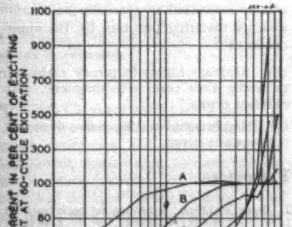
pliers) is well known, we shall be satisfied here with a reference[3] to the subject.

The capacity of the 180-cycle static generator shown in Figure 7 is 400 volt-amperes and weighs about 25 pounds. The 180-cycle power input into the 69-kv current transformers of Table I is 42 watts at about 90 per cent power factor, and that into the 161-kv unit of Table II 70 watts. The harmonic generator therefore can supply excitation to a number of current transformers.

The harmonic generator is too large a load for potential transformers installed for metering service.



(a). Core loss



(b). Exciting current

Figure 4. Excitation characteristics of magnetic cores (wound strip) when excited simultaneously at different flux densities at 60-cycles and at triple frequency

Core density (kilolines per square inch), 60 cycles

A—2,500 lines per square inch, 180 cycles
B—7,500 lines per square inch, 180 cycles
C—15,000 lines per square inch, 180 cycles
D—25,000 lines per square inch, 180 cycles
E—32,250 lines per square inch, 180 cycles

Accuracy Characteristics

The ratio and phase-angle characteristics of two such bushing-current transformers, one for 69-kv and the other for 161-kv circuits, are exhibited in detail in Tables I–III.

The significance of these exhibits as to the improvements accomplished may be gathered from a few of the items listed. For instance, for the 161-kv unit for 150/5 amperes with wye-burden, the following figures are found in Table II:

	At 0.5 Ampere		At 5.0 Amperes	
	Ratio Error, Per Cent	Phase Angle, Minutes	Ratio Error, Per Cent	Phase Angle, Minutes
Plain current transformer	−6.7	+262.	−4	72
180-cycle excitation added	−1.5	+ 12.	−1.6	13
Z and auto-transformer also added	−0.56	+ 4.	−0.43	0

The maximum ratio error is seen to have been cut down from 6.7 per cent to 0.56 per cent; the phase-angle error, from 262 minutes to 4 minutes. In the final result, as the ratio error varies between −0.43 per cent and −0.56 per cent, it follows that if the measurements are multiplied by 1.005, the maximum ratio error of the result will be no more than 0.05 per cent, that is, about $^1/_{20}$ of one per cent.

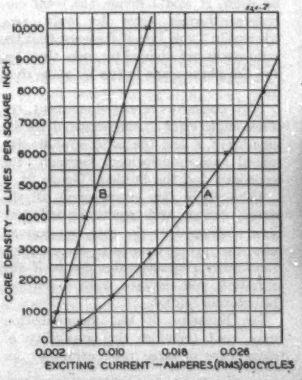


Figure 5. Exciting current of wound-strip magnetic cores with and without auxiliary triple-frequency excitation

A—60 cycles
B—60 cycles plus 180 cycles (32,250 lines per square inch)

Effect of Voltage Fluctuations

Variations in the current-transformer accuracy under fluctuations of the supply voltage to the harmonic generator also were investigated, and it was found that a ten per cent range of voltage fluctuation made a difference of 0.1 per cent in the ratio error and one minute in the phase-angle error.

Wave Shape

Figure 6 shows oscillograms of primary and secondary currents. In order to make the higher-frequency component more conspicuous in case it should find its way into the 60-cycle circuits, the higher-frequency excitation was furnished at 540 cycles for these oscillograms. No trace of such a harmonic was visible in any of the oscillograms taken.

In one test, in order to determine accurately any possible induced harmonic current in the secondary circuit unmixed with any fundamental-frequency current, the secondary current was measured under full triple-frequency excitation and *no primary current*, and it was found to be about one-tenth of one per cent of the rated current of the winding. Needless to add, no matter how large the harmonic current, it cannot affect the wattmeter indications unless a corresponding harmonic voltage, inphase with the harmonic current, also is impressed across the potential coils of the meters.

Freedom From Residual Magnetism

Those familar with this subject know that current-transformer accuracy tests do not always reproduce themselves on account of varying values of residual magnetism, unless the core is demagnetized carefully before each test.[5] The present type, with a constant demagnetizing excitation, is free from this uncertainty.

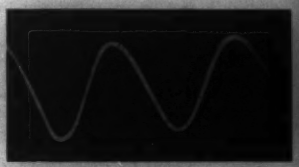


Figure 6a. Wave shape of the primary current with 0.5-ampere secondary current, no high frequency

Figure 6b. Wave shape of the secondary current, 0.5 ampere, with 540-cycle auxiliary excitation

Magnetization Curves

Figure 4 gives typical magnetization data taken on a wound-core unit made up of silicon-steel strip and subjected to 60-cycle and 180-cycle excitations simultaneously. Figure 4a gives the watt-loss data and Figure 4b, the exciting-current data. To bring out the benefit of dual excitation more clearly and quantitatively, ordinates give the losses (watt or exciting current) as a percentage of the corresponding values in the absence of auxiliary excitation. It is seen that in the range of the flux densities to be encountered in bushing-transformer practice (1–10 kilolines per square inch), impressive reductions in watt losses and exciting current are accomplished when a 180-cycle excitation is superimposed at a density of 25–30 kilolines per square inch: the watt losses are cut down to a half, and the exciting current to a third. Other test data, not reproduced here, show that, up to about 60-kiloline 60-cycle density, the benefit of this auxiliary excitation is practically unaffected by the phase displacement between the two excitations.

Impressive as these curves may be, they exhibit only one factor in the improved accuracy of the current transformer through such auxiliary excitation. The more important factor, as intimated above, is the possibility of the conversion of the nonlinear magnetization curve into a linear one by appropriate auxiliary excitation, so that the errors first may be rendered constant and then be compensated for by other means. Any reduction is, of course, a gain, insofar as it reduces the necessary compensation to that extent, but the possible error reduction by the linearization-and-compensation method is many times that by the exciting-current reduction method.

Figure 5 exhibits the straightening of the magnetization curve very clearly. Curve *A* applies to the normal 60-cycle volt-ampere characteristic of the core without auxiliary excitation, curve *B* to the 60-cycle characteristic with the benefit of a 180-cycle auxiliary excitation maintained at about 30 kilolines per square inch.

So far as the absolute value of the exciting current is concerned, curve *B* is only about 50 per cent better than *A*.

Figure 7. View of a frequency-tripling transformer; rated output 400 volt-amperes

Primary voltage = 240 volts; secondary voltage, 120 volts

It is not so good as what might have been obtained with seventh harmonic or with higher triple-frequency excitation; and, by itself, it would divide the total current-transformer error by only two, whereas in Table II—*Y*, it is seen that the ratio errors are divided by more than ten and the phase-angle errors by more than 60.

With the errors rendered constant, the phase-angle error is compensated for by impedance *Z* and the ratio error by the tapped autotransformer between the secondary and the burden (Figure 3).

Although in this arrangement all the power, active and reactive, including those consumed by the core, are derived from the primary circuit, the current-transformer characteristics are as if the excitation volt-amperes were a part of the external burden.

The linearity of the magnetization curve, and therefore the possibility of taking care of large ratio errors by an autotransformer, greatly simplifies the problem of correcting the phase-angle error by the impedance *Z*. This impedance may be chosen conveniently over a surprisingly wide range of power factor and magnitude, because it is not a serious matter if *Z* is chosen somewhat injudiciously and, although fully correcting the phase-angle error, renders the ratio error worse than before, inasmuch as this additional ratio error can be taken care of by some other tap on the autotransformer.

In some of the cases reported in the tables, *Z* consisted of a resistance in series with an inductance.

Conclusions

It is shown that bushing-type current transformers, which in their simple form would not be good enough for metering, can be converted to precision units suitable for metering purposes by the application of

(*a*). Auxiliary higher-frequency excitation to render their cores orthomagnetic, with constant errors.

(*b*). Simple compensating means to correct the constant errors.

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Compressed-Air Circuit Breakers in A-C Railway Service

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Synopsis: The increasing interest in compressed air as an interrupting and operating medium for circuit breakers in central-station and industrial service, together with its gratifying record in service periods extending up to five years, warrants investigation of its application to a-c railway service. Previous developments leading up to present standards of requirement for this service are reviewed, and a description is given of a compressed-air breaker designed for high-speed interruption of short circuits on contact line feeders in single-phase 25-cycle railway service at 12,000 volts to ground. Application of the principle to other railway service is discussed.

TWENTY years have passed since the first circuit breakers designed to afford speed protection for contact lines in 11,000-volt single-phase 25-cycle railway service were installed on the Danbury branch of the New Haven Railroad.[1] Using oil as an interrupting medium, these breakers were designed to detect and interrupt, in conjunction with high-speed relaying, short circuits on contact lines in 0.04 second, one cycle on a 25-cycle wave, representing a long step in advance of then existing oil-breaker practice. These three breakers are still in service today in their original application, although increased power to meet the demands of heavier traffic may necessitate their replacement by breakers with rupturing ability beyond their moderate rating in the foreseeable future.

Tests made with these breakers in their service position demonstrated their ability to meet specified time requirements and indicated that this performance might be expected to reduce damage to overhead installations and motive equipment to a minimum, as well as insure satisfactory continuity of service on parallel signal and communication circuits. Accordingly, this specification as to time performance, 0.04 second or less, has remained standard up to the present day. It should be stated, however, that high-speed equipment in railway service shows a considerable proportion of interruptions after a single loop of short-circuit current when the zero point in the a-c wave is favorably located.

In the years immediately following this installation another important electrification project required the provision of high-speed breakers with interrupting ability up to 50,000 amperes at 12,000 volts to ground, and in 1928 two new designs; one an air-insulated breaker,[2] the other an oil-insulated breaker,[3] were installed in considerable numbers on the four-track main-line electrified zone of the Pennsylvania Railroad from Philadelphia to Wilmington,[4] later extended to Washington. Both designs followed earlier practice in their own fields, the air breaker being an extension to moderate alternating voltages of the magnetic-blowout principle then in operation for a number of years in d-c railway service, and the oil breaker following fundamentals of the original New Haven breaker but with considerably improved mechanical details. Both breakers were developed with the aid of high-power testing equipment then becoming available with sufficient power to demonstrate their performance.

Preparatory to this large main-line project, an exhaustive investigation of requirements for relay protection had been made,[5] and the results were here put into practical effect. One noticeable result of this investigation may be noted in the conclusion reached that the use of a d-c shunt tripping magnet for opening the high-speed breaker tends toward greater flexibility in protective relaying, and this form of tripping is now regarded with favor for the service.

By 1930 this electrified zone had been considerably extended,[6] and another air-insulated high-speed breaker had appeared, operating on the then newly developed deion theory of arc rupture. This breaker was demonstrated by test to be the equal in service ability of previous designs and was installed in considerable numbers on further extensions of the system. Essentially of the indoor class of construction, it represented a forward step in application, considering the amount of organic material incorporated at critical points of insulation in its interrupting chamber with possibilities of deterioration in outdoor service. As protection against such possibility, the breaker structure was enclosed in a weatherproof steel housing with double walls, interposing an annular air space around the breaker to minimize the effects of condensation. Space heaters were provided further to reduce this effect. Breakers of this class have now been in continuous service adjacent to the Jersey Meadows for 12 years without more than the normal deterioration to be expected for that period in any service. This experience has demonstrated effectively the feasibility of applying organic insulation in outdoor service when adequate protection is afforded.

By 1935 concentrations of power at rail-junction points on this system had increased to such extent that the previously accepted interrupting rating of 50,000 amperes for high-speed breakers was clearly inadequate for certain feeder positions. It became evident that, as an alternative to a rather extensive rearrangement of feeders, a costly operation at the best, breakers of greater interrupting capacity must be developed for this service, and the new interrupting specification was set at 65,000 amperes as meeting all requirements in the foreseeable future. This demand brought out a fourth design, another oil-insulated breaker of the impulse type,[7] now in service at various points on the system.

As a result of the service experience obtained with the varying types of equipment on this electrified system in the years since full-scale operation was put into effect, together with the information obtained from several years of trial operation preceding it,[8] the requirements for

Figure 1. An early form of high-speed breaker

This oil breaker was the first high-speed interrupter to be placed in service at 12,000 volts

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Figure 2. A more modern high-speed oil breaker

Incorporating fundamental principles of its predecessor, but with improved mechanical details, this breaker was installed in considerable numbers

protection of contact lines in 12,000-volt railway service, the type of protective relaying,[8] and the arrangement of substation equipment had become clearly identified, and standards of performance had been fixed. Development of new lines of apparatus for this service must then consist largely of adaptation of more modern devices to its use.

Outstanding among interrupting mediums today is compressed air, applied in the form of a transverse blast for maximum current interruption at voltages in the powerhouse class. Five years of experience in service operation with conventional-speed breakers in powerhouse duty, together with a laboratory-testing record which has made the compressed-air breaker the most completely tested device in the upper range of current interruption ever offered to the trade, render it most desirable for application to heavy-duty a-c railway service.

Even more desirable, such application does not involve extreme exploration into untried avenues of development. The breaker parts proper, including the contact elements, arc chute, muffler, blast tube, and blast valve, may be taken bodily from conventional-speed breakers service-proved for the equivalent interrupting duty in other applications. Since a latched-in type of mechanism is best adapted to a rapid start of acceleration of the moving contact on opening, the design of high-speed latch and d-c tripping magnet proved by 15 years of service in previous designs of high-speed breakers for railway service may be utilized in its present form. The high-speed linkage with its accelerating device and contact connecting rod may be substantially the same as in earlier breakers, modified only to adapt it to a new position in the breaker structure. Compressed air being available as an interrupting medium, it is logical to utilize it for the conventional-speed closing function; hence a conventional air-closing cylinder. There remains, then, only to co-ordinate these features into a single operating unit.

Figure 4 shows a breaker of such design meeting the present specification of 65,000 amperes interrupting capacity at 12,000 volts to ground, single phase, 25 cycles, with an interrupting time of 0.04 second or less in conjunction with high-speed relaying, and with a potential withstanding test of 65,000 volts for one minute. Mounted in a weatherproof steel housing with double walls, incorporating the annular air space of earlier designs, the complete structure is divided into three compartments. The lowermost compartment carries the air reservoirs, operating mechanism, and all low-voltage control equipment. Immediately above it, isolated by a horizontal grounded barrier, is the main breaker compartment enclosing the high-potential breaker parts. At the top of the structure is an expansion or diffusion chamber, enclosed by the cupola form of roof construction and isolated from the main breaker compartment by a horizontal insulating barrier. The arc chute discharges the air blast with its heated arc products through a muffler into this diffusion chamber from which it is vented to atmosphere through louvered openings. Conductors are brought through the roof of the housing to the breaker terminals by conventional condenser bushings of 34.5-kv rating.

Doors are provided at the front and rear of the housing allowing full access to all parts of the breaker. The doors of the two main compartments are separated, permitting access to mechanism and controls without exposure to high-potential parts. Footings have been designed to permit installation on the same foundation as earlier designs of high-speed breaker, facilitating replacement of those breakers in positions where breakers of lower rupturing ability have become inadequate, because of increased power requirements. The condenser bushings, while incorporating refinements of modern design, are interchangeable with those of earlier breakers.

The contact details and their arrangement with respect to the air blast and arc chute conform to the conventional practice previously presented before the Institute.[9] The conventional blade and finger type of contact is used on this design in contrast to the butt-type contacts of earlier high-speed breakers to provide the overlapping contact travel necessary to insure full amplitude of blast air at the time of contact parting. The blast valve is of the conventional metal-to-metal-seat poppet type, mechanically operated by a

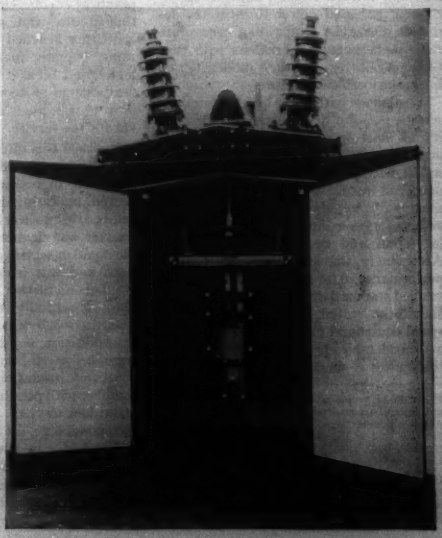


Figure 3. The deion high-speed breaker

Incorporating the deion principle of arc rupture, this breaker is rendering valuable interrupting service up to 50,000 amperes

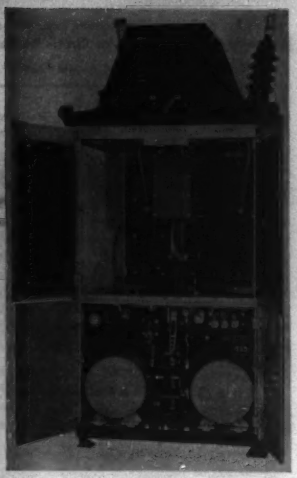


Figure 4. Compressed-air high-speed breaker

Embodiment of a modern compressed-air interrupting device renders this breaker capable of handling the heaviest railway service

cam surface on the trip-free lever when opening, but arranged to be inoperative on the breaker closing stroke since the air blast is not essential in circuit closing.

Application of accelerating force to the moving contact on opening differs slightly in this breaker from the practice in previous high-speed breakers with their short follow-up of butt-type contacts. There it was necessary to concentrate the accelerating force at the start of motion in order to obtain the highest speed possible at contact parting, and to continue this acceleration in order to insure a contact gap sufficient to withstand voltage when the arc has been swept onto arcing horns in the extinguishing process.

In the compressed-air breaker a somewhat more moderate accelerating force with the longer contact follow will produce the same contact speed at parting and, while the arc is maintained on the contacts, interruption may be allowed to occur at a shorter contact gap since the presence of blast air increases the dielectric strength of the gap. This increase in dielectric strength of the contact gap reduces the possibility of arc re-establishment on voltage restoration. As a further advantage the decelerating force may be applied earlier in the opening stroke, bringing the contact to rest more easily and reducing stresses on the mechanism.

Table I shows the results of a single series of interrupting tests made in the high-power laboratory with a compressed-air high-speed breaker. Power was obtained from two 60,000-kva generators operating in parallel at 11,000 volts, 25 cycles. Current values were limited by the station reactors. The tests were made phase to phase, ungrounded, this circuit having recovery rates varying with the currents interrupted from 500 to 810 volts per microsecond, giving an interrupting condition somewhat more severe than the bonded-rail return circuit in railway service. The shunt tripping magnet of the breaker was energized by a high-speed relay actuated in turn by the bushing-type current transformers supplied as a part of the breaker.

Figure 6A shows the interrupting performance of the breaker at moderate short-circuit-current values, 14,800 amperes, on a rather highly asymmetrical wave. On this test the contacts parted just at or slightly before the end of the first loop but had not reached a gap sufficient for interruption, and current continued to flow through the second loop, completing interruption in one full cycle. Because of the offset wave, this cycle, measured on the zero line, actually required 0.041 second to complete. Voltage disturbance at the final zero was quite limited. The tripping coil was energized in approximately 0.006 second after the start of flow of short-circuit current and remained energized for about one cycle, being interrupted by a mechanically operated cutout contactor during the opening stroke of the breaker. Blast air continued for 1.5 cycles after interruption, thus insuring complete deionization of the arc path.

In order to insure that the breaker has reserve rupturing ability beyond its current rating of 65,000 amperes, interrupting tests were made with short-circuit currents up to 20 per cent above this rating. Figure 6B shows its performance when interrupting 79,500 amperes. The magnetic effect of the current loop through the breaker increased the speed of contact travel on this test, and parting occurred sufficiently early to permit interruption at the first current zero, resulting in a single loop of short-circuit current of 0.031-second duration. No voltage disturbance accompanied the interruption. The oscillographic record of blast air shows some effect of the pressure of arc gases in a single peak during the period immediately preceding interruption, but the rapid drop from this peak at the current zero shows how completely these gases were scavenged before current could flow in the reverse direction.

The cathode-ray record, Figure 7, shows the voltage condition accompanying the interruption of 41,000 amperes on one of these tests. The circuit-recovery rate was 810 volts per microsecond with a frequency of 12,500 cycles. This is not a particularly high recovery rate from the viewpoint of switching experience on 60-cycle utility and industrial-distribution circuits, but it is believed to be appreciably higher than any to be encountered in 25-cycle contact-line-feeder circuits. It will be noted that the first peak of recovery voltage is only slightly above normal restored voltage, whereas the high-frequency oscillations are damped out into natural frequency after approximately 0.003 second. On no test did the first peak of recovery voltage reach a value of twice normal voltage.

Air-compressing equipment for a supply of air to these breakers is installed in a separate housing designed for mounting on any foundation for the breakers.

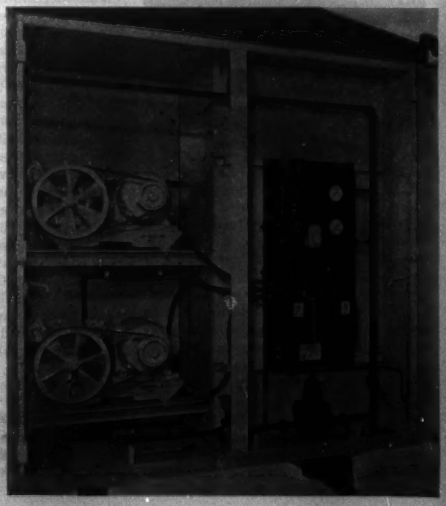
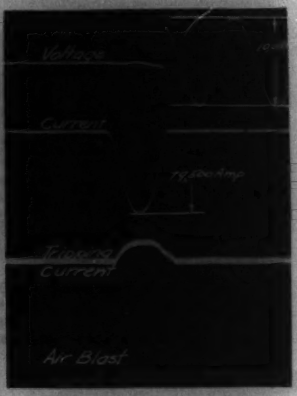


Figure 5. Air-compressing equipment

Motor-driven compressors, automatic-control, cooling coils, and storage reservoirs are assembled in a compact unit

A. Interrupting 14,800 amperes



B. Interrupting 79,500 amperes

Figure 6. Oscillographic records of high-speed compressed-air-breaker tests

The air-supply unit shown in Figure 5 is designed for installations of one or two breakers where there is little prospect of future additions. This unit is equipped with two belt-driven two-stage air-cooled compressors, each with a delivery of approximately 4.4 cubic feet per minute of free air, permitting use of one compressor for service while the other is out for inspection or maintenance. Normally both compressors are running. For a larger bank of breakers requiring two or more supply units, a single compressor per unit with a higher delivery rating is recommended.

Normal operating pressure for air-storage reservoirs in the supply unit is 250 pounds per square inch, a reducing feed valve automatically maintaining a working pressure of 150 pounds per square inch in the air-delivery system to the circuit-breaker reservoirs. Compressors and motors with their control are located in an enclosed portion of the housing with double walls, supplied with space heaters to insure that they will be operative under the most severe temperature conditions. The storage reservoirs are located in an open portion of the housing, protected only by expanded metal panels. Air intakes for the compressors are carried to the outside of the enclosure.

Operation of the air-supply unit is controlled automatically by a pressure governor set to cut off the compressor motor when storage pressure reaches 250 pounds per square inch, and to cut it in again when pressure has been reduced to some predetermined lower value. An additional pressure switch is set to operate an alarm if pressure becomes reduced to a point requiring attention of an attendant.

Special care has been taken in the design of the air-supply unit to reduce the moisture content of the air before it is delivered to the circuit breakers. In addition to an intercooler between stages of compression, air from the discharge valve of the high-compression cylinder of the compressor passes through an aftercooler of finned copper tubing to the first storage reservoir, whence it passes through a second aftercooler to the second storage reservoir, carrying the outlet to the air-delivery system. Both reservoirs operate at a normal pressure of 250 pounds per square inch.

These coolers are designed to reduce the air from its high temperature on leaving the compressor to ambient temperature at the outlet to the delivery lines, condensing the vapor content of the air in the process and depositing it in the storage reservoirs where provision is made for its drainage. Since the storage reservoirs themselves are exposed to ambient temperature, little or no further condensation takes place after the air leaves the supply unit, and adequately dry air for circuit breaker operation is assured.

For other railway service, not requiring high-speed interruption, such as generator or transformer breakers in powerhouse or substation duty, conventional-speed indoor breakers are available for operating voltages from 11,000 to 33,000 in three-pole (three-phase) or two-pole (single-phase) form for interrupting duty from 500,000 kva upward. These breakers, normally designed for eight-cycle interruption on a 60-cycle basis, may be expected to complete interruption in three cycles after a tripping impulse when applied in 25-cycle service. Following conventional powerhouse practice, compressed air is used in these breakers for both closing and opening breaker operations, air being admitted on either side of the main operating piston as desired.

Table I. A Series of Interrupting Tests With a High-Speed Compressed-Air Circuit Breaker

11,000 Volts, 25 Cycles, Single Phase

Test No.	Initial Voltage, Kv	Current Interrupted, Amperes	Duration of Short Circuit, Seconds	Restored Voltage, Kv
1	11.0	14,900	0.042	11.2
2	11.0	14,700	0.043	11.2
3	11.0	14,650	0.044	11.2
4	11.0	18,900	0.041	11.1
5	11.0	19,300	0.040	11.2
6	11.0	18,800	0.041	11.3
7	11.0	30,600	0.033	11.1
8	11.0	30,600	0.033	11.1
9	11.0	30,400	0.033	11.1
10	11.0	44,000	0.033	11.1
11	11.0	43,400	0.031	10.8
12	11.0	44,000	0.033	10.8
13	11.0	44,600	0.031	10.85
14	11.0	58,000	0.031	10.7
15	11.0	57,800	0.029	10.7
16	11.0	56,500	0.030	10.5
17	11.0	68,500	0.034	10.4
18	11.0	67,000	0.032	10.5
19	11.0	68,500	0.031	10.5
20	11.0	78,000	0.029	10.4
21	11.0	80,000	0.030	10.5
22	11.0	79,500	0.031	10.5

Conclusions

The use of compressed-air circuit breakers in powerhouse and substation duty has advanced sufficiently far in the United States to assure its reliability for service. The extension of this interrupting medium to high-speed equipment for protection of contact line feeders in 12,000-volt 25-cycle single-phase railway service has now been accomplished, and its ability to meet reliably the specified time requirements for this service has been demonstrated by full-scale tests.

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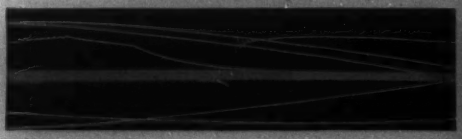

Figure 7. Typical cathode-ray oscillogram of test with compressed-air high-speed breaker

Rectifier Fault Currents

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CURRENTS in excess of normal, or fault currents, flow in rectifier circuits under conditions of arc-back or d-c short circuit. In normal service, faults are imposed on rectifiers by both the arc-backs that occur in the rectifier itself and the short circuits that occur in the external d-c system. Rectifier units must, therefore, include suitable protective switchgear to limit the magnitude and duration of the fault currents in order to

1. Prevent damage to the rectifier, transformer, and other parts.

2. Limit the disturbance on the a-c and d-c systems.

The determination of the fault currents in power rectifiers is essential to the design of rectifier and transformer equipment capable of withstanding the short-circuit forces, the selection of suitable protective switchgear, and the setting of relay and breaker trip mechanisms.

A wide variety of circuit combinations may be obtained under fault conditions, and many are of such complexity that accurate calculation of the instantaneous fault currents is difficult, if not impracticable. However, a complete determination of the instantaneous fault currents under all the possible conditions is not essential. Sufficient information for the design and application of rectifier equipment may usually be obtained from maximum values of the instantaneous and sustained currents.

This paper presents fault-current analyses for the widely used delta double-wye connection. The methods are also applicable to other connections. Three basic types of rectifier faults are considered in the analyses. Most rectifier faults can be resolved into one of these types, which are:

1. D-c short circuit.
2. Arc-back in a wye.
3. Arc-back with d-c feed.

Power rectifiers of the single-way type usually employ a rectifier transformer having interlaced secondary windings. Windings on the same leg of the transformer core are interlaced to obtain minimum losses and optimum reactance relationships. Various types of construction may be used; for example, two windings may be interlaced by winding the two coil conductors side by side in a single structure, by alternating pancake coils in a stack, or by alternating concentric coils. Many modifications are possible which meet the essential requirement that the current sheaths produced by the interlaced coils occupy essentially the same space distribution with respect to the primary so that they have common leakage-flux paths.

The usual rectifier circuit has negligible reactance in the transformer secondary circuit as the transformer secondary windings are interlaced, the anode leads are generally short, and anode reactors of appreciable reactance are seldom used. Under these conditions, all the circuit reactance may be considered to be located in the transformer primary and supply line.

The short-circuit analysis which follows treats the general case with primary reactance. The special case where all the reactance is located in the secondary leads has been treated in previous analyses.[1]

D-C Short Circuit

Sustained D-C Short-Circuit Current

A typical double-wye rectifier circuit is shown in Figure 1a and the usual transformer construction is indicated in Figure 1b. When such a rectifier is short-circuited at its d-c terminals the fault currents have the characteristic forms shown in Figure 2.

The transformer secondary currents (per phase) on sustained d-c short circuit are the same as on a-c short-circuit impedance test when all the reactance is located in the transformer primary and supply line. Under these conditions each rectifying element carries a current wave of sinusoidal form and 180 degrees duration, one of the two secondary coils on each phase carrying the positive half cycle of current, while the other carries the negative half cycle. The a-c short-circuit current may be calculated as for a standard power transformer, and the sustained d-c short-circuit current is obtained by changing rms to average values.

The rms short-circuit current, I_s', per pair of interlaced secondary coils on each phase is

$$I_s' = \frac{E_s}{X} \tag{1}$$

where

E_s = transformer secondary line-to-neutral voltage in rms volts

X = reactance per phase in ohms line to neutral

The average d-c short-circuit current in amperes, I_{sc}, obtained by averaging the current for the three phases is

$$I_{sc} = 3\frac{2\sqrt{2}}{\pi} I_s' \tag{2}$$

The ohmic reactance, X, may be expressed in terms of the per unit transformer reactance, $\underline{X}$, referred to the volt-ampere base, VA.

$$X = \frac{3E_s^2}{VA}\underline{X} \tag{3}$$

When the necessary substitutions in equation 2 are made,

$$I_{sc} = \frac{2\sqrt{2}}{\pi}\frac{VA}{E_s}\frac{1}{\underline{X}} \tag{4}$$

In calculating the sustained short-circuit current the reactance of the a-c supply $\underline{X}_L$ may be added directly to that of the transformer $\underline{X}_T$ to obtain the total reactance, that is, $\underline{X} = \underline{X}_T + \underline{X}_L$.

The resistance of the transformer windings is generally small in comparison with their reactance and does not alter the circuit action appreciably. The effect of resistance of the transformer windings therefore may be included readily in the short-circuit calculations by substituting the impedance for the reactance in equation 4. If $\underline{R}$ is the per unit resistance per phase, the per unit impedance is

$$\sqrt{\underline{R}^2 + \underline{X}^2}$$

An approximate correction for the effect of arc drop may be made by assuming that the arc drop during short circuit is a sinusoidal voltage of constant rms value, E_b, which is in phase with the current and subtracts from the applied voltage. The voltage relations are then as shown in the vector diagram in Figure 3 and the net voltage acting in the circuit is E_s'. The short-circuit current is reduced in the

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ratio E_s'/E_s because of the arc drop. The solution for this ratio is

$$\frac{E_s'}{E_s} = \sqrt{1-\left(\frac{E_b}{E_s}\frac{X}{\sqrt{R^2+X^2}}\right)^2} - \frac{E_b}{E_s}\frac{R}{\sqrt{R^2+X^2}} \quad (5)$$

The final expression for the sustained d-c short-circuit current including the effect of resistance and arc drop is then

$$I_{sc} = \frac{2\sqrt{2}}{\pi}\frac{VA}{E_s\sqrt{R^2+X^2}}\frac{E_s'}{E_s} \quad (6)$$

If the volt-ampere base, VA, is equal to the rated input volt-amperes of the double-wye rectifier transformer with theoretical current wave shape, that is,

$$VA = \frac{\pi}{3}E_{do}I_{dn} = \frac{\sqrt{3}}{\sqrt{2}}E_sI_{dn} \quad (7)$$

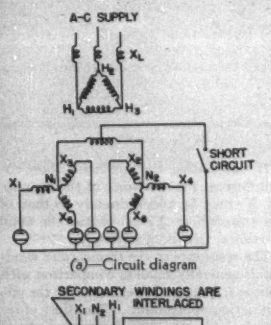
where

E_{do} = theoretical direct voltage
I_{dn} = direct current at rated output

The expression for sustained short-circuit direct current may be written:

$$I_{sc} = \frac{2\sqrt{3}}{\pi}\cdot\frac{I_{dn}}{\sqrt{R^2+X^2}}\cdot\frac{E_s'}{E_s} \quad (8)$$

Equation 8 holds only for the double-wye circuit, but equation 6, which is expressed in terms of volt-amperes, applies



(a)—Circuit diagram

(b)—Transformer construction

Figure 1. Double-wye rectifier

to any single-way circuit with a three-phase supply. For a double-way circuit, I_{sc} will be equal to one-half the value given by equation 6.

Rate of Rise of D-C Short-Circuit Current

The rate of rise of d-c short-circuit current immediately following the time of

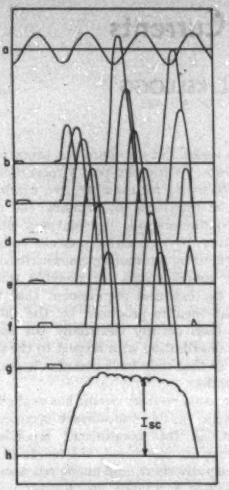


Figure 2. D-c short-circuit oscillogram

(a)—Timing wave
(b) to (g)—Anode currents
(h)—Short-circuit current

fault depends on: the number of phases feeding into the fault, the inductance L of each phase, the inductance L_0 of the fault path, and the arc drop E_a of the rectifying elements. The maximum rate of rise for a double-wye rectifier is obtained when three phases, 60 degrees apart, conduct. The crest value of the average voltage of the three phases in parallel is equal to $(2\sqrt{2}/3)E_s - E_a$. If this voltage is impressed on the rectifier inductance $L/3$ and the fault path inductance, the maximum rate of rise is obtained.

$$\left(\frac{di}{dt}\right)_{max} = \frac{(2\sqrt{2}/3)E_s - E_a}{(L/3)+L_0} \quad (9)$$

In system studies involving short-circuit conditions it is often helpful to represent a rectifier unit by a simple machine having equivalent voltage, inductance, and resistance such that its action approximates the average behavior of the rectifier. While the rectifier circuit action does not remain the same throughout the range of operation from normal load to short circuit, representative values for the equivalent voltage, inductance, and resistance may be selected on the following basis:

The output voltage of a double-wye rectifier at no load is

$$E_{do} = \frac{3\sqrt{3}}{\pi\sqrt{2}}E_s = 1.17E_s \quad (10)$$

and is obtained with an anode conduction period of 120 degrees. The conduction period increases with load, very rapidly at first and more slowly as short-circuit conditions are approached. Under sustained d-c short circuit the anode conduction period is 180 degrees and the average voltage is

$$E_{do}' = \frac{2\sqrt{2}}{\pi}E_s = 0.90E_s \quad (11)$$

This voltage does not appear at the rectifier terminals, but is the internal electromotive force of the rectifier. Under conditions approaching short circuit the anode conduction period is nearly 180 degrees and the equivalent voltage of the rectifier unit may therefore be assumed to be $0.90\,E_s$.

Since two anodes are normally conductive in a double-wye rectifier at light load, the equivalent inductance of the rectifier unit is $L/2$. Under sustained d-c short circuit three anodes are normally conductive. However, at any instant one secondary wye has one anode conductive while the other secondary wye has two anodes conductive. The interphase transformer tends to maintain parallel operation between these two dissimilar circuits as at light load. It has been found that good agreement between calculated and tested values of rate of rise of current on d-c short circuit is obtained if the equivalent inductance of the rectifier unit under transient conditions is assumed to

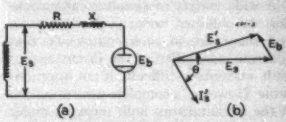


Figure 3. Arc-drop correction for sustained d-c short circuit

(a)—Circuit diagram
(b)—Vector diagram

be $L/2$. Similarly, the equivalent resistance may be assumed to be $R/2$.

Using the foregoing empirical relations, the rate of rise of short-circuit current of the equivalent unit is

$$\frac{di}{dt} = \frac{0.90E_s - E_a}{(L/2)+L_0} \quad (12)$$

This formula is used to determine the calculated values of the rate of rise of short-circuit direct current referred to in the section on comparison of calculated and test results.

Arc-Back in a Wye

The fault conditions covered by this case are obtained when an arc-back occurs on a single-wye rectifier operating with d-c circuit open or connected to a pure resistance load and is sustained after steady-state conditions are reached. The fault circuit is shown in Figure 4a.

The arc-back current under steady-state conditions in a delta double-wye rectifier without d-c feed arises principally from the other two anodes in the same wye as the faulty anode. The cur-

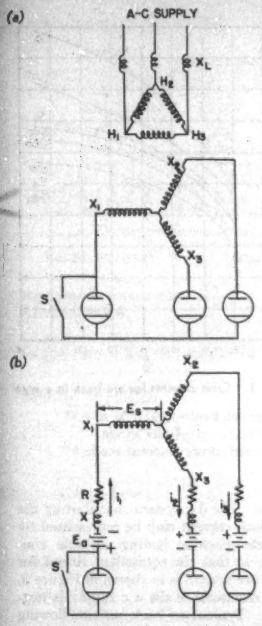


Figure 4 (left). Arc-back in a wye

(a)—Circuit diagram
(b)—Equivalent circuit

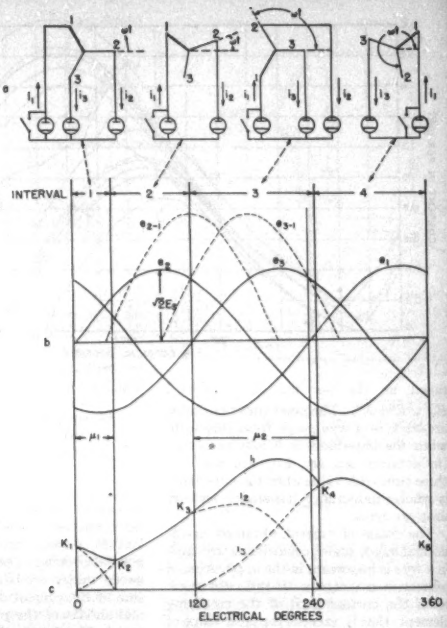


Figure 5 (right). Arc-back in a wye

(a)—Circuit diagrams
(b)—Voltages
(c)—Currents

rent contribution of the anodes on the other wye is limited to a low value by the impedance of the interphase transformer and the interlacing of the two secondary coils of each phase of the rectifier transformer.[2] Another factor in limiting this contribution is the long conduction period of the anodes of the faulted wye. The analysis of arc-back current when there is no d-c feed, therefore, reduces to an analysis of the current in a single wye with one anode arcing back and two normal anodes. The equivalent circuit is shown in Figure 4b.

In the equivalent circuit the open-circuit voltages of the three phases of the wye are assumed to be sinusoidal voltages 120 degrees apart having maximum values equal to $\sqrt{2}\,E_s$. Each phase of the transformer is assumed to have an inductance L and a resistance R and each rectifying element to have a constant arc drop E_a, which may be represented by a counter electromotive force.

Each cycle may be divided into four intervals having different combinations of conducting phases. The vector relations and circuit arrangement for each of these intervals are shown in Figure 5a, where the cycle is assumed to start at a time such that the open-circuit secondary voltages are

$$\left.\begin{aligned} e_1 &= \sqrt{2}E_s \sin\left(\omega t+\frac{2\pi}{3}\right)\\ e_2 &= \sqrt{2}E_s \sin \omega t\\ e_3 &= \sqrt{2}E_s \sin\left(\omega t-\frac{2\pi}{3}\right)\end{aligned}\right\} \quad (13)$$

The secondary voltages on open circuit and the secondary currents under arc-back are shown in Figures 5b and 5c, respectively, where i_1 is the instantaneous current in the faulted phase and i_2 and i_3 are the currents in the two normal phases.

The instantaneous current during each interval may be calculated by the application of Kirchhoff's laws to the network and the solution of the resulting differential equations.

If the cycle is assumed to start when the voltage e_2 is equal to zero, the following relations may be written for the first interval:

$$e_2-e_1-L\left(\frac{di_2}{dt}+\frac{di_1}{dt}\right)-R(i_2+i_1)-2E_a=0 \quad (14)$$

and

$$e_3-e_1-L\left(\frac{di_3}{dt}+\frac{di_1}{dt}\right)-R(i_3+i_1)-2E_a=0 \quad (15)$$

as

$$e_1+e_2+e_3=0$$

and

$$i_1=i_2+i_3$$

By substitution

$$\frac{di_1}{dt}+\frac{R}{L}i_1=\frac{\sqrt{2}E_s}{L}\sin\left(\omega t-\frac{\pi}{3}\right)-\frac{4}{3}\frac{E_a}{L} \quad (16)$$

whose solution is

$$i_1=\frac{\sqrt{2}E_s}{\sqrt{R^2+L^2\omega^2}}\left[\sin\left(\omega t-\frac{\pi}{3}-\gamma\right)+\epsilon^{-\frac{Rt}{L}}\sin\left(\frac{\pi}{3}+\gamma\right)\right]-\frac{4}{3}\frac{E_a}{R}\times\left[1-\epsilon^{-\frac{Rt}{L}}\right]+K_1\epsilon^{-\frac{Rt}{L}} \quad (17)$$

where

$$\gamma=\tan^{-1}\frac{L\omega}{R}$$

Similar expressions may be derived for the current during each interval. The current equations for all four intervals are summarized in the appendix.

In order to determine the crest value of the current in both the faulty and the normal phases under steady-state conditions it is necessary to construct the current waves. The construction of the current waves may be made by choosing values of the ratios X/R and $E_a/\sqrt{2}E_s$, assuming a value for the initial current, K_1, and making successive trial solutions of the equations until the condition $K_1=K_4$ is satisfied. Figure 6 shows the fault-current waves calculated from the above equations when $E_a/\sqrt{2}E_s=0.05$.

The crest values of the fault currents under steady-state conditions are plotted as a function of X/R on Figure 7 for $E_a/\sqrt{2}E_s=0$, 0.05, and 0.10. The crest current obtained with the three terminals of the wye short-circuited directly is

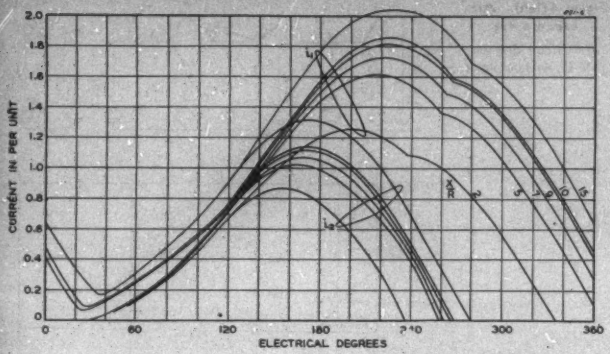


Figure 6. Current waves for arc-back in a wye

Per unit base = $\sqrt{2}E_s/\sqrt{R^2+X^2}$
i_1 = faulty anode current
i_2 = normal anode current

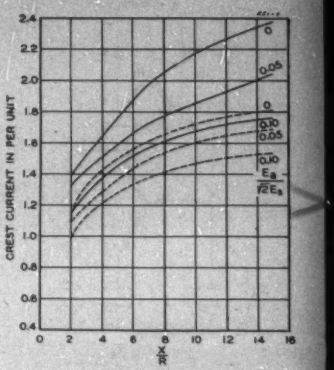


Figure 7. Crest currents for arc-back in a wye

Per unit base = $\sqrt{2}E_s/\sqrt{R^2+X^2}$
Solid curves—Faulty anode
Dotted curves—Normal anode

taken as the per unit base, $I=\sqrt{2}E_s/\sqrt{R^2+X^2}$. The crest currents during arc-back in a wye range from this value when the impedance is wholly resistance (inductance and arc drop are zero), to three times this value when the impedance is wholly inductance (resistance and arc drop are zero).

The value of current obtained in the normal anode under condition of arc-back in a wye is important in the application of protective switchgear. If this current exceeds the current limit of the rectifying element, that is, exceeds the crest value of current which the rectifying element can carry without arc-back during the succeeding inverse period, simultaneous arc-backs will be obtained on several anodes. Under such conditions, the benefits accruing from the use of selective individual anode breakers would be largely lost and excessive duty would be incurred on the rectifier equipment.

Arc-Back With D-C Feed

In many applications rectifiers are arranged to operate in parallel with other converting equipment, such as d-c generators, synchronous converters, or other rectifiers; or to supply power to counter-electromotive-force loads, such as motors or electrolytic cells. Arc-back in a rectifier connected to such a system is equivalent to a short circuit on both the a-c and d-c circuits. The current in the faulty anode under arc-back conditions is the sum of the current delivered by the normal anodes of the rectifier and the current feedback from the d-c system.

A typical rectifier installation with several double-wye-connected rectifiers operating in parallel is shown in Figure 8. Under arc-back conditions with the usual circuit constants the two normal anodes on the same wye with the faulted anode, are the only ones in the rectifier delivering appreciable current into the faulted anode as the current from the anodes connected to the other wye is limited by the impedance of the interphase transformer and the effect of the interlacing of transformer windings.[1] The d-c feed-back current is supplied by the normal rectifiers connected in parallel with the rectifier which is arcing back, together with the other converting equipment and counter-electromotive force-load connected to the d-c system. The d-c system contributing the feed-back current may be represented by a single machine having suitable constants, so that the equivalent circuit for the entire system is as shown in Figure 9, if the reactance of the a-c supply is neglected. Typical arc-back currents flowing in such a circuit are indicated in Figure 10.

Where several rectifiers operate in parallel on a common bus the current in the faulty anode during arc-back is substantially equal to the feed-back current, as the inductance of the equivalent machine supplying the feed-back current is low in comparison with the inductance of the winding connected to the faulted anode and the current contribution from the normal anodes on the same wye may be neglected. If the current contribution from the normal anodes on the same wye is neglected, the system may be represented by a series circuit with a direct voltage E_d', an alternating voltage $\sqrt{2}\,E_s \sin(\omega t+\beta)$, an arc drop E_a, a total inductance L_d, and a total resistance R_d as shown in Figure 11. The formulas which follow

Table I. Comparison of Calculated Versus Test Values of Rectifier Fault Currents

Rectifier Rating		Circuit Constants				D-C Short Circuit				Arc-Back in a Wye		Arc-Back With D-C Feed			
		Transformer				Sustained Amp		Rate of Rise Amp Per μsec		Faulty Anode Crest Amp		Amp at One-Half Cycle		Rate of Rise Amp Per μsec	
Kw	Volts	Kva	X	R	E_s	Calc	Test	Calc	Test	Calc	Test	Calc	Test	Calc	Test
150	240	184	0.126	0.027	340	5,200	4,720	0.99	1.23						
1,500	3,000	1,590	0.073	0.008	2,840	7,260	7,100*	1.78	2.18*	6,060	7,100†§				
3,000	3,009	3,210	0.083	0.005	2,366	14,700	11,800	1.44	1.53	14,300	10,600†				
1,675	515	1,685	0.037	0.008	568	65,000	47,000	11.4	8.6						
1,675	515	1,925	0.071	0.006	500	47,000	43,900**	8.65	7.15**	41,600	41,300	62,000	46,000‡	10.0	8.42‡
3,250	650	7,500	0.115	0.006	612							83,200	54,200	11.8	8.18
3,250	650	7,500	0.079	0.006	612							92,700	79,400#	14.2	14.2#

* Figure 12.
** Figure 2.
§ See Figure 13.
† Includes contribution of all normal anodes.
‡ Feed-back current in cathode.
# Figure 14.

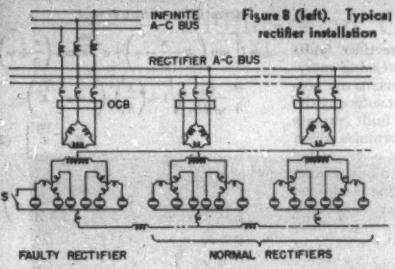
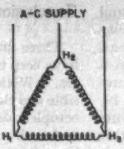


Figure 8 (left). Typical rectifier installation



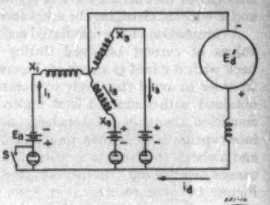


Figure 9 (top right). Equivalent circuit for arc-back with d-c feed

are based on such a simplified circuit. By Kirchhoff's law:

$$L_d \frac{di}{dt} + R_d i = \sqrt{2} E_s \sin(\omega t + \beta) + E_d' - E_a \quad (18)$$

Solution for i yields

$$i = \frac{E_d' - E_a}{R_d}\left[1 - e^{-\frac{R_d}{L_d} t}\right] + \frac{\sqrt{2} E_s}{\sqrt{R_d^2 + L_d^2 \omega^2}}\left[\sin(\omega t + \beta - \gamma) - e^{-\frac{R_d}{L_d} t} \sin(\beta - \gamma)\right] \quad (19)$$

where

$$\gamma = \tan^{-1} \frac{L_d \omega}{R_d}$$

In these formulas, the angle β is the phase angle of the line-to-neutral voltage of the faulty phase at the time of arc-back.

Maximum fault currents are obtained when the arc-back occurs immediately following conduction. As most double-wye rectifiers operating without phase control have an angle of overlap between 20 and 25 degrees at rated load, β will have negative values of five to ten degrees. However, in determining maximum fault currents no appreciable error will be incurred by assuming $\beta = 0$.

Comparison of Calculated and Test Results

In order to check the validity of the assumptions made in the derivation of the foregoing formulas and determine the accuracy with which fault currents may be calculated by these formulas, a number of comparisons between tests and calculated values have been made. The results of these checks are shown in Table I. Typical oscillograms showing fault current obtained under a number of the conditions are shown in Figures 2, 12, 13, and 14.

With reference to the results given in Table I, the fault currents obtained in test are generally lower than the calculated values. One reason for this is that the reactance and resistance of the interphase transformer, anode leads, d-c bus bars, and the short-circuiting loop are neglected in most calculations as these quantities are difficult to determine and are usually small. Another is the effect of saturation of the transformer core by the d-c components of fault current. When the transformer saturates, the voltage drop in the supply line is increased because of the high exciting current required by the transformer. Furthermore, the actual supply-system reactance is frequently higher than the assumed values, as such values are generally based on full generating capacity.

The effect of phase control has not been considered in these analyses as the most severe fault currents are obtained when operating with no phase control. The effect of phase control depends upon the kind of rectifier excitation employed and the part of the cycle during which it permits the start of anode conduction, as the voltage across the rectifying element is shifted in phase under fault conditions.

The effects of arc-drop must be included in the calculation of fault currents if accurate results are desired, particularly for rectifiers at 600 and 250 volts. The value of the arc-drop under fault conditions depends upon the type of rectifying element employed and the magnitude of the fault current.

An average arc drop of 100 volts has been assumed in the calculations for the 600- and 3,000-volt rectifiers given in Table I, and an average arc drop of 50 volts for the 250-volt rectifier.

Typical d-c short-circuit currents are shown in Figures 2 and 12. Both these oscillograms show an initial transient current exceeding the sustained value. The effect is particularly pronounced in Figure 12. This high initial fault current is caused by a displacement of the transformer currents similar to that obtained on three-phase a-c short-circuit tests.

A typical oscillogram of the current in the faulty anode during arc-back in a wye is shown in Figure 13. This test was made on a six-anode rectifier and the fault current therefore includes the contribution of all five normal anodes. The current wave form should be compared with the calculated waves shown in Figure 6.

With five normal anodes feeding into the faulty anode, some current will flow through the interphase as the fault is maintained. The effect of this current is to lower the current contribution of the

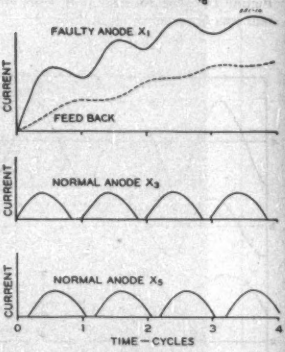


Figure 10. Typical current waves for arc-back with d-c feed

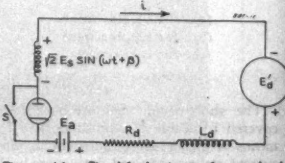


Figure 11. Simplified circuit for arc-back with d-c feed

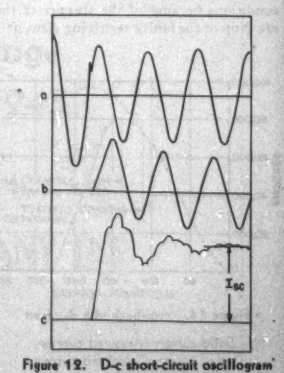


Figure 12. D-c short-circuit oscillogram

(a)—A-c supply voltage
(b)—A-c supply current
(c)—Short-circuit current

normal anodes in the faulty wye and smooth out the current wave in the faulty anode without changing the crest current.

A comparison of the calculated and test values of current obtained during arc-back with d-c feed is shown in Figure 14. In order to avoid the severe overcurrents obtained with sustained feed under this condition, the anode breakers begin circuit interruption in less than one half cycle and a check on ultimate sustained values cannot be obtained. In the case shown in Figure 14 some reduction in fault current was obtained in one half cycle.

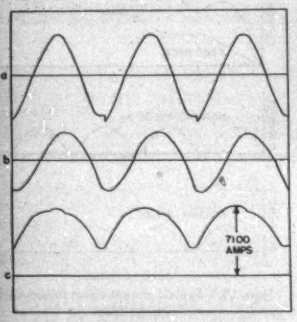


Figure 13. Arc-back in a wye oscillogram

(a)—A-c supply voltage
(b)—A-c supply current
(c)—Arc-back current

The short-circuit and arc-back tests covered by Table I were all applied by means of a short-circuiting switch. The current values obtained during arc-back with d-c feed are therefore higher than would be obtained under actual arc-back conditions because of the absence of the arc drop of the faulty rectifying element.

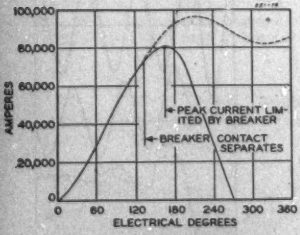


Figure 14. Arc-back with d-c feed

Solid curve—Measured current
Dotted curve—Calculated current

Conclusions

Three basic types of rectifier faults have been treated in the foregoing analyses. While other arrangements are possible and the analyses do not suffice for the complete determination of fault currents under all conditions, the formulas which have been derived provide a means for calculating the maximum values of fault current under certain limiting conditions usually encountered in service. Inasmuch as the duty on the rectifier, transformer, and switchgear depends in large measure upon the maximum current, the determination of the instantaneous current throughout the duration of the fault is usually not essential. The expressions for fault current which have been derived are based on a number of assumptions and are therefore only approximate. However, they afford a better understanding of the circuit action during faults and provide means for predicting fault-current magnitudes with greater accuracy than heretofore has been possible.

Appendix I. Symbols

I_{sc} = sustained d-c short-circuit current in average amperes
I_{da} = rated direct current of rectifier in average amperes
E_a = transformer-secondary line-to-neutral voltage in rms volts
E_{da} = theoretical direct voltage in average volts, assuming no overlap, no phase control, and zero arc drop
E_d' = open-circuit voltage of the equivalent d-c machine
E_a = average arc drop, in volts
E_b = sinusoidal voltage equal to the fundamental component of E_a, in rms volts
X = line-to-neutral reactance at the transformer-secondary terminals in ohms
$\underline{X}$ = per unit reactance
$L = X/\omega$
$\omega = 2\pi f$, where f = frequency of a-c supply
L_d = inductance of simplified circuit for arc-back with d-c feed in henrys
R = line-to-neutral resistance at the transformer secondary terminals in ohms
$\underline{R}$ = per unit resistance
R_d = resistance of simplified circuit for arc-back with d-c feed in ohms
VA = per unit volt-ampere base
K = current constant in amperes

Appendix II. Arc-Back in a Wye (Current Equations)

Let $X = L\omega$, $I = \sqrt{2}E_a/\sqrt{R^2+L^2\omega^2}$, and $\gamma = \tan^{-1}\frac{L\omega}{R}$.

Interval 0 to u_1 where $\theta_1 = \omega t$:

$$i_1 = I\left[\sin\left(\omega t-\frac{\pi}{3}-\gamma\right)+\epsilon^{-\frac{R\theta_1}{X}}\sin\left(\frac{\pi}{3}+\gamma\right)-\frac{4}{3}\frac{E_a}{\sqrt{2}E_a}\sqrt{1+\left(\frac{X}{R}\right)^2}\left(1-\epsilon^{-\frac{R\theta_1}{X}}\right)+K_1\epsilon^{-\frac{R\theta_1}{X}}\right] \quad (20)$$

and

$$i_2 = I\left[\sin\left(\omega t+\frac{\pi}{3}-\gamma\right)+\epsilon^{-\frac{R\theta_1}{X}}\sin\left(\frac{\pi}{3}-\gamma\right)-\frac{2}{3}\frac{E_a}{\sqrt{2}E_a}\sqrt{1+\left(\frac{X}{R}\right)^2}\left(1-\epsilon^{-\frac{R\theta_1}{X}}\right)+K_1\epsilon^{-\frac{R\theta_1}{X}}\right] \quad (21)$$

Interval u_1 to $\frac{2\pi}{3}$: where $\theta_2 = (\omega t - u_1)$:

$$i_1 = I\left[\frac{\sqrt{3}}{2}\sin\left(\omega t-\frac{\pi}{6}-\gamma\right)-\frac{\sqrt{3}}{2}\epsilon^{-\frac{R\theta_2}{X}}\sin\left(u_1-\frac{\pi}{6}-\gamma\right)-\frac{E_a}{\sqrt{2}E_a}\sqrt{1+\left(\frac{X}{R}\right)^2}\left(1-\epsilon^{-\frac{R\theta_2}{X}}\right)+K_2\epsilon^{-\frac{R\theta_2}{X}}\right] \quad (22)$$

Interval $\frac{2\pi}{3}$ to $\left(\frac{2\pi}{3}+u_2\right)$ where $\theta_3 = \left(\omega t-\frac{2\pi}{3}\right)$:

$$i_1 = I\left[\sin\left(\omega t-\frac{\pi}{3}-\gamma\right)-\epsilon^{-\frac{R\theta_3}{X}}\sin\left(\frac{\pi}{3}-\gamma\right)-\frac{4}{3}\frac{E_a}{\sqrt{2}E_a}\sqrt{1+\left(\frac{X}{R}\right)^2}\left(1-\epsilon^{-\frac{R\theta_3}{X}}\right)+K_3\epsilon^{-\frac{R\theta_3}{X}}\right] \quad (23)$$

and

$$i_2 = I\left[\sin(\omega t-\gamma)-\epsilon^{-\frac{R\theta_3}{X}}\sin\left(\frac{2\pi}{3}-\gamma\right)-\frac{2}{3}\frac{E_a}{\sqrt{2}E_a}\sqrt{1+\left(\frac{X}{R}\right)^2}\left(1-\epsilon^{-\frac{R\theta_3}{X}}\right)+K_3\epsilon^{-\frac{R\theta_3}{X}}\right] \quad (24)$$

Interval $\left(\frac{2\pi}{3}+u_2\right)$ *to* 2π where $\theta_4 = \left(\omega t-\frac{2\pi}{3}-u_2\right)$:

$$i_1 = I\left[-\frac{\sqrt{3}}{2}\cos(\omega t-\gamma)+\frac{\sqrt{3}}{2}\epsilon^{-\frac{R\theta_4}{X}}\times\cos\left(\frac{2\pi}{3}+u_2-\gamma\right)-\frac{E_a}{\sqrt{2}E_a}\sqrt{1+\left(\frac{X}{R}\right)^2}\times\left(1-\epsilon^{-\frac{R\theta_4}{X}}\right)+K_4\epsilon^{-\frac{R\theta_4}{X}}\right] \quad (25)$$

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1. Mercury Arc Power Rectifiers (book), O. K. Marti, H. Winograd, pages 66–80.

2. A New Multiple High-Speed Air Circuit Breaker for Mercury-Arc-Rectifier Anode Circuits and Its Relation to the Arc-Back Problem, J. W. Seaman, L. W. Morton. AIEE Transactions, volume 61, 1942, November section, pages 788–96.

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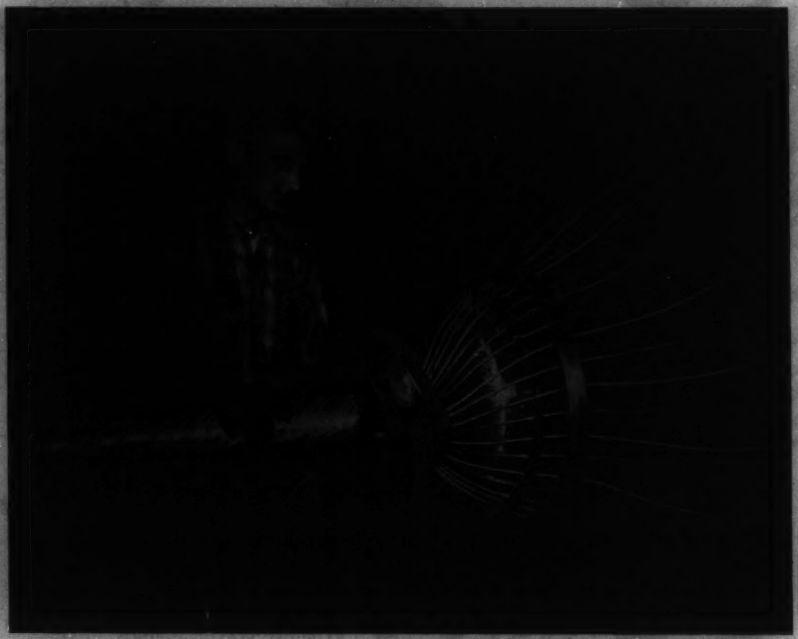

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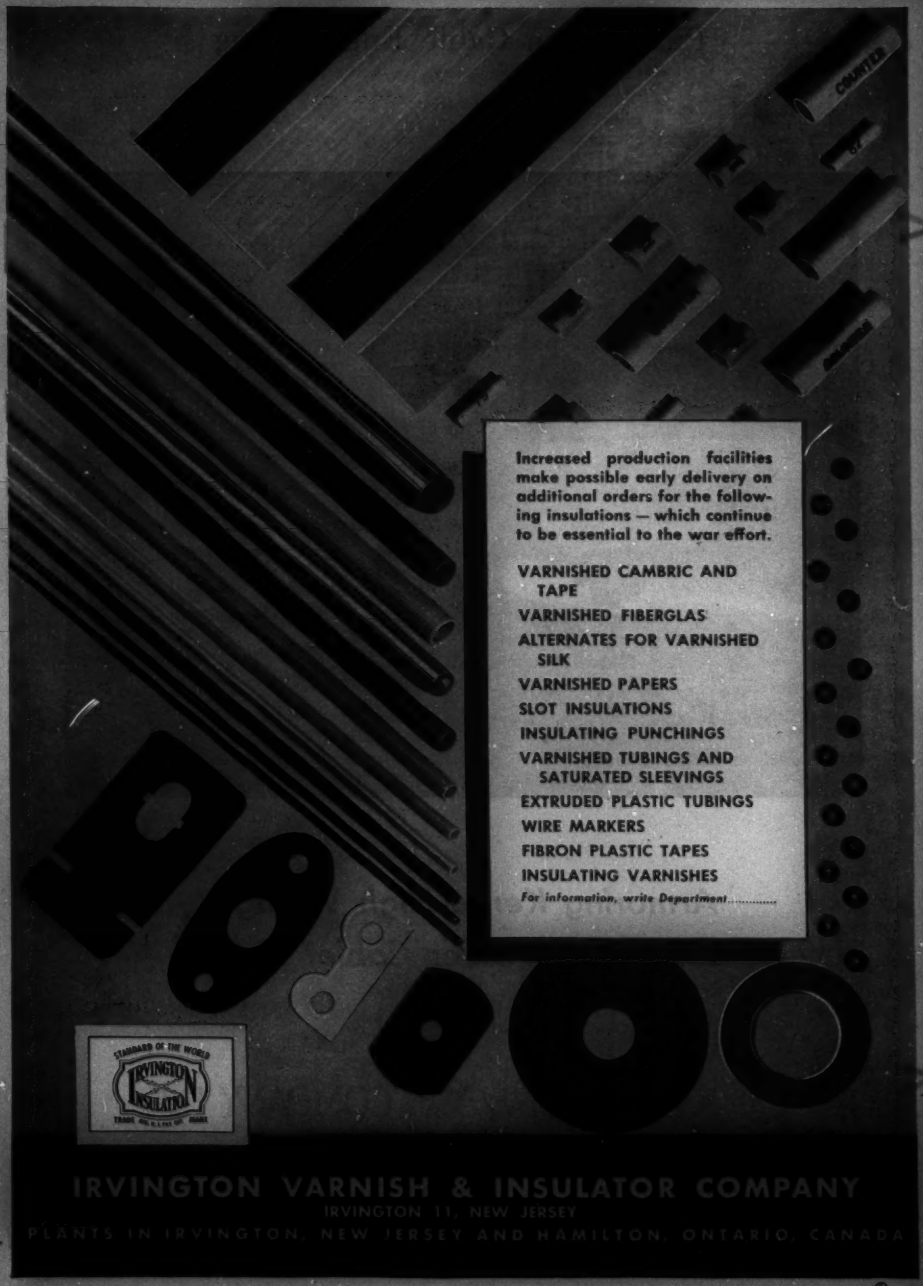
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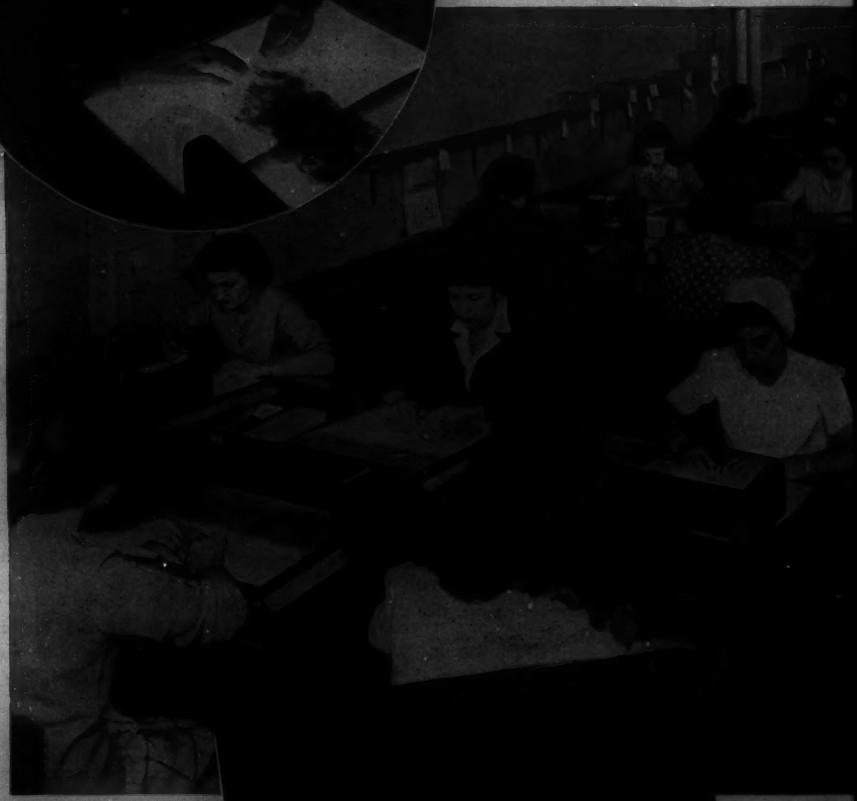

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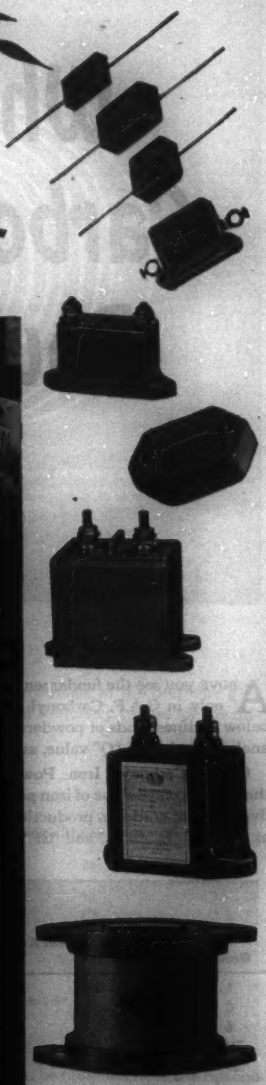

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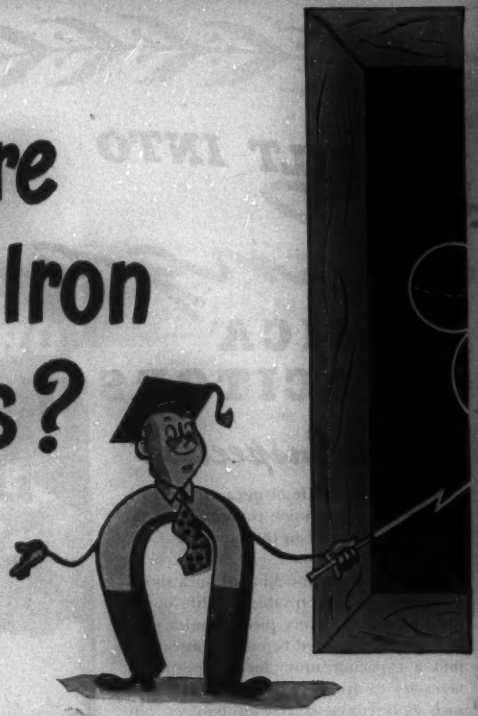

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G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, which are designated as "L," "C," "E," "TH," and "SF" Powder.

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The chemical analysis, the weight-average particle size, the "tap density," and the apparent density as determined in a Scott Volumeter are given in the following table for the five different grades:

TABLE 1

Grade	Chemical Analysis % Carbon	% Oxygen	% Nitrogen	Wt. Ave. diameter microns	Tap Density g/cm3	Apparent Density g/cm3
L	0.005—0.03	0.1 —0.2	0.005—0.05	20	3.5—4.0	1.8—3.0
C	0.03 —0.12	0.1 —0.3	0.01 —0.1	10	4.4—4.7	2.5—3.0
E	0.65 —0.80	0.45—0.60	0.6 —0.7	8	4.4—4.7	2.5—3.5
TH	0.5 —0.6	0.5 —0.7	0.5 —0.6	5	4.4—4.7	2.5—3.5
SF	0.5 —0.6	0.7 —0.8	0.5 —0.6	3	4.7—4.8	2.5—3.5

With reference to the chemical analysis shown above, it should be noted that spectroscopic analysis shows the rest to be iron with other elements present in traces only.

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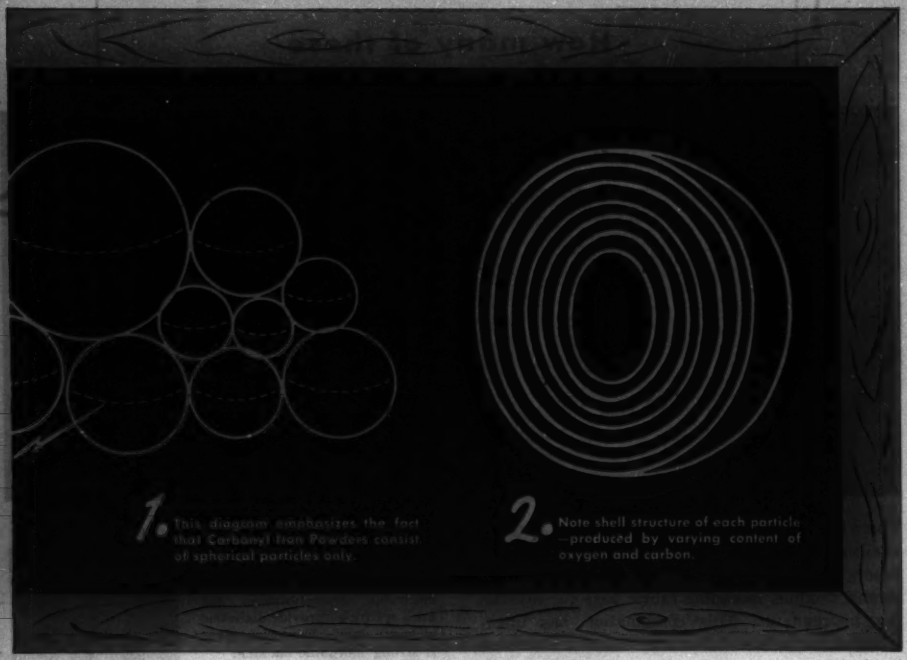
Table 2 at right gives relative Q values (quality factors) and effective permeabilities for the different grades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of carbonyl iron powder. The values given in the table are derived from measurements on straight cylindrical cores placed in simple solenoidal coils. Although the data were not obtained at optimum conditions, the Q values as expressed in percentage of the best core give an indication of the useful frequency ranges for the different powder grades.

TABLE 2

Carbonyl Iron Grade	Effective Permeability at 1 kc	Relative Quality Factor at 10 kc	150 kc	200 kc	1 Mc	100 Mc
L	4.16	100	96	90	43	1
C	3.65	94	100	98	72	3
E	3.09	81	94	100	97	30
TH	2.97	81	93	98	100	54
SF	2.17	62	71	78	84	100

(Note: The actually measured Q values can be obtained by multiplying the rows respectively with: 0.78, 1.09, 1.25, 2.63, and 1.62.)

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Fiberglas Varnished Cloth and Tape... Made by many manufacturers who impregnate various types of Fiberglas Cloth with several kinds of varnishes. These products are available in 36" widths or cut to any desired tape width.

Fiberglas Mica Combinations . . . The combination of thin glass cloths with mica for ground insulation is not dependent upon impregnating varnish for its electrical characteristics; the mica splittings provide dielectric strength while Fiberglas gives it strong inorganic backing.

Fiberglas Laminates . . . Most manufacturers of electrical laminates make one or more types of Fiberglas base materials. The finished materials are used in motors and generators as slot sticks, armature or stator end laminations, brush holders, space blocks, etc. The low power factor obtainable has resulted in increasingly wide use in radio and electronic applications.

Write for booklet . . . It tells what type to use, where and how. Send for your copy today, and ask for the name of the Fiberglas Electrical Insulation Materials supplier located nearest to you . . . Owens-Corning Fiberglas Corporation, 1859 Nicholas Bldg., Toledo 1, Ohio. In Canada, Fiberglas Canada Ltd., Oshawa, Ontario.

Each Distributor of Fiberglas-base Insulation Materials has his own source of supply; none of these processed insulations is made by Owens-Corning Fiberglas Corporation.

FIBERGLAS

*T. M. Reg. U. S. Pat. Off.

ELECTRICAL INSULATION MATERIALS

BE SURE TO SEE THE FIBERGLAS ELECTRICAL INSULATION MATERIALS EXHIBIT

THE NEXT SHOWINGS ARE: Hotel Statler, Buffalo, February 27-March 1; Biltmore, Dayton, March 7-9; Netherlands Plaza, Cincinnati, March 13-15; Hotel Henry Grady, Atlanta, March 20-21; Hotel Tutwiler, Birmingham, March 27-28.

ANNOUNCING

ELECTRICAL SPECIALTY COMPANY, 316 Eleventh Street, San Francisco 3, California
INSULATION & WIRES, INC., 2127 Pine Street, St. Louis 3, Missouri
INSULATION MANUFACTURERS CORPORATION, 565 Washington Blvd., Chicago 6, Illinois
MICA INSULATOR COMPANY, 200 Varick Street, New York 14, New York
NATIONAL ELECTRIC COIL COMPANY, Columbus 16, Ohio
PREHLER ELECTRICAL INSULATION CO., 564 West Monroe Street, Chicago 6, Illinois
WESTINGHOUSE ELECTRIC & MANUFACTURING CO., Trafford, Pa.

DISTRIBUTORS FOR

DC
993 VARNISH

Essential to High Temperature Silicone Insulation

Rapidly growing demands for DC-993 Silicone Varnish are being filled from stocks of the above newly-appointed distributors.

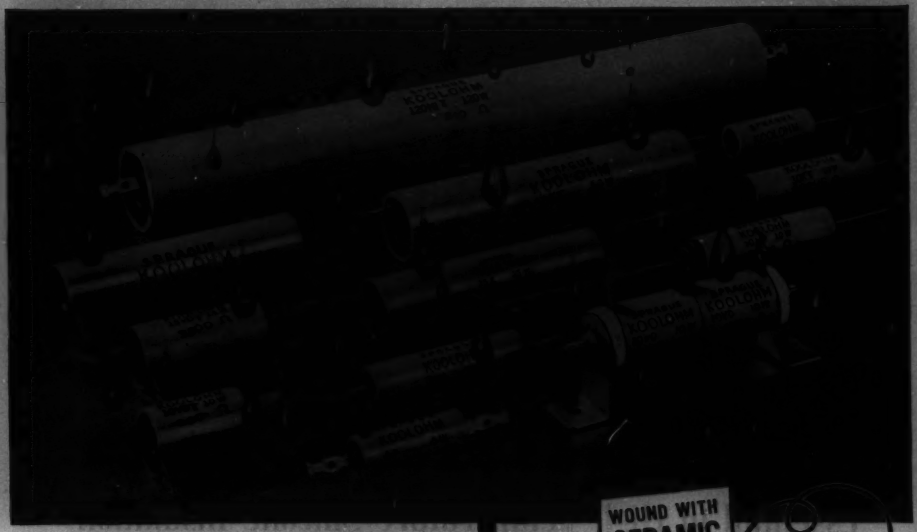
Through these representative sources of supply, Dow Corning, first producer of Silicones, is able to extend the application of this revolutionary insulating material—a heat curing, high temperature stable, moisture-proof silicone varnish destined for an important place in the new age of electrical machinery and equipment.

DOW CORNING CORPORATION
BOX 592, MIDLAND, MICHIGAN

JUST OFF THE PRESS—This new eight-page book on DC-993 Silicone Varnish is now available from any of the distributors listed above. Write for a copy. It will give you comprehensive technical information on this new insulating material and its applications.

Dow Corning
FIRST IN SILICONES

Now! EXTRA HUMIDITY PROTECTION IS STANDARD



. . . designed for tropical conditions
. . . unbeatable on ANY job

Standard Sprague Koolohm Wire Wound Resistors now offer the same high degree of humidity protection formerly obtainable only on special order to match exacting military specifications. This construction, newly adopted as standard, includes a glazed ceramic outer shell and a new type of end seal. These features give maximum protection against even the most severe tropical humidity conditions. Type numbers remain the same except for the fact that the letter "T" has been added to designate the new standard construction.

Thus, again, Sprague leads the way in practical, truly modern wire wound resistor construction. Your job of resistor selection is greatly simplified. No need to study and choose between types or coatings. One type of Koolohms, the *standard* type, does the job —under any climatic condition, anywhere in the world!

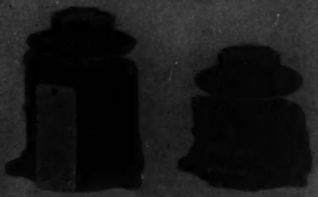
SPRAGUE ELECTRIC COMPANY, North Adams, Mass.
(formerly Sprague Specialties Co.)

SPRAGUE KOOLOHM RESISTORS

TRADEMARK REGISTERED U.S. PAT. OFF.

The Greatest Wire-Wound Resistor Development in 20 Years

A NEW VARIAC FOR 400 TO 2600 CYCLES



200-CU
60 ~

NEW 60-AU
400-2600 ~

SAME POWER RATING

UNIT BRUSH — REPLACED IN A FEW SECONDS

POSITIVE ROTOR CONTACT WITH NO PIGTAILS

DESIGNED for an increasing number of applications requiring the control of power at frequencies higher than 60 cycles, this new VARIAC meets the need for a unit for frequencies between 400 and 2600 cycles. It is a companion to the widely used Type 200-A having substantially the same power rating . . . . . 860 va; with a load current of 5 amperes, rated, and a maximum current of 7.5 amperes near zero and line voltages.

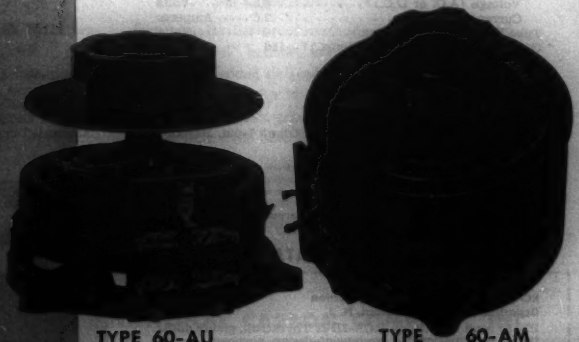
A number of new mechanical features are incorporated in the Type 60-A VARIAC. Included are:

- New unit brush construction requiring no tools for brush replacement and designed to prevent contact between brush holder and winding when the brush wears away
- Positive rotor contact with NO pigtail
- Combination screw and solder terminals
- Fully insulated hollow steel shaft
- Improved bearings, suitable for motor drive

As seen in the photograph, the Type 60-A VARIAC is considerably smaller than its 60-cycle counterpart. The Type 60-AU is priced at $13.00 and the 60-AM at $15.00.

Because all VARIAC production is scheduled months in advance on high priority war orders for 60-cycle models, these new VARIACS are now available only in sample quantities.

- **WRITE FOR BULLETIN 923**



TYPE 60-AU

TYPE 60-AM

VARIAC

MADE ONLY BY

GENERAL RADIO COMPANY

Cambridge 39, Mass.

NEW YORK
CHICAGO
LOS ANGELES

NEW Xenon-Filled Thyratron

RCA 3D22

Moderately priced; rugged, single-ended construction; operates in any position; designed for relay and grid-controlled-rectifier applications, particularly those involving electronic speed-control of small D-C motors

LIST PRICE **$10.75**

¾-Ampere Average Continuous Current. The 3D22 is a sensitive, four-electrode thyratron conservatively rated to handle an average output of 0.75 ampere in continuous operation and a peak current of 6 amperes.

Single-ended, Sturdy, Compact Construction. Sturdily and compactly constructed for industrial service, the 3D22 is single-ended and requires no flexible leads for connections.

Control-Characteristic Stable Over Wide Temperature Range. Because Xenon gas is used, the control-characteristic is essentially independent of ambient temperature.

Low Preconduction Current and Low Control-grid Current. The low preconduction current and the low control-grid current permit the use of a high-value grid resistor to give increased sensitivity with a high-impedance circuit.

TECHNICAL DATA

ELECTRICAL

Heater for Unipotential Cathode:		
Voltage (A.C. or D.C.)*	6.3 ± 10%	Volts
Current	2.6	Amperes
Tube Voltage Drop (Approx.)	10	Volts
Grid. No. 1 Control Ratio (Approx.)†	150	

PHYSICAL

Mounting Position	Any
Maximum Overall Length	4⅛"
Maximum Diameter	2⅜"
Base	Medium Metal Shell Giant 7-pin, Bayonet

**Heater voltage must be applied at least 30 seconds before start of tube conduction.*
†For conditions with 0.1-megohm grid resistor and grid No. 2 volts = 0.
‡Averaged over any 30-second interval.

RELAY AND GRID-CONTROLLED RECTIFIER SERVICE

Maximum Ratings, Absolute Values

Peak Forward Anode Voltage	650 *max.*	Volts
Peak Inverse Anode Voltage	1300 *max.*	Volts
Peak Cathode Current	6 *max.*	Amperes
Average Cathode Current‡	0.75 *max.*	Ampere
Ambient Temperature Range	−75 to +90	°C

WRITE FOR ADDITIONAL DATA

MAIL TODAY!

RCA, Commercial Engineering Section
Department 62-29A, Harrison, N. J.

Please send bulletin on RCA-3D22 Thyratron, giving additional information for equipment-design purposes.

Name .....

Company .....

Address .....

City ..... State .....

RCA

RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION · CAMDEN, N. J.

THE FOUNTAIN-HEAD OF MODERN TUBE DEVELOPMENT IS RCA

How To Be an "ESOFHMBP"*

*Expert Solver of Fractional Horsepower Motor Brush Problems

FIRST you build, staff and equip a complete laboratory for the purpose. Next, make available to it all the experience and knowledge gained from a half century of brush manufacturing. Then, we believe, you can give our type of brush testing service.

Others, it seems, agree. For more and more electric motor manufacturers are submitting their *present* and *postwar* models to our Fractional Horsepower Motor Brush Testing Laboratory for brush recommendations.

Thanks to recent improvements in our manufacturing facilities and methods, speedier deliveries of "National" brushes are now being made. And helping to speed deliveries is this modern laboratory which enables National Carbon Company to recommend brush grades more promptly and accurately than ever before.

We urge you to get in touch with our nearest Division Office for full information on how to submit motors for brush testing under *your own* specified load, temperature, humidity, altitude or other conditions.

The word "National" is a registered trade-mark of National Carbon Company, Inc.

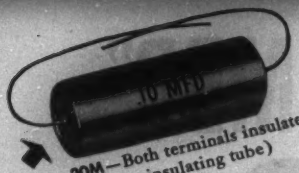
KEEP YOUR EYE ON THE INFANTRY . . .
THE DOUGHBOY DOES IT!

NATIONAL CARBON COMPANY, INC.
Unit of Union Carbide and Carbon Corporation

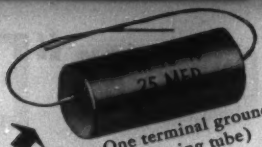
UCC

General Offices: 30 East 42nd Street, New York 17, N. Y.

Division Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco



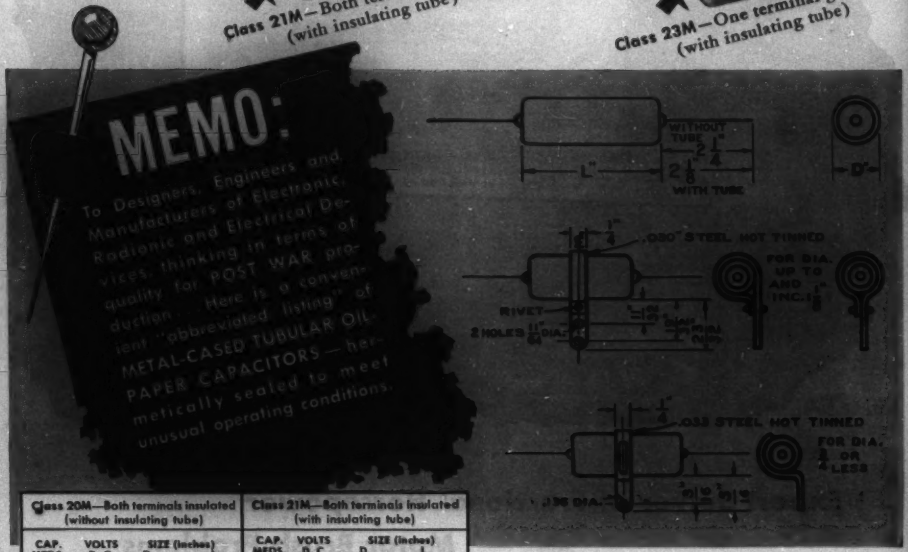
Class 20M—Both terminals insulated (without insulating tube)



Class 22M—One terminal grounded (without insulating tube)

Class 21M—Both terminals insulated (with insulating tube)

Class 23M—One terminal grounded (with insulating tube)


MEMO:
To Designers, Engineers and Manufacturers of Electronic, Radionic and Electrical Devices, thinking in terms of quality for POST WAR production. Here is a convenient "abbreviated listing" of METAL-CASED TUBULAR OIL PAPER CAPACITORS—hermetically sealed to meet unusual operating conditions.
WITHOUT TUBE
WITH TUBE
L"
D"
.030" STEEL, NOT TINNED
FOR DIA. UP TO AND INCL. 1"
RIVET
2 HOLES DIA.
.033 STEEL, NOT TINNED
FOR DIA. 3/4 OR LESS

Class 20M—Both terminals insulated (without insulating tube)			
CAP. MFDS.	VOLTS D. C.	SIZE (inches) D.	L.
.001	1000	1/2	1-3/16
.0025	1000	1/2	1-3/16
.005	1000	1/2	1-3/16
.005	600	3/8	15/16
.01	600	3/8	1-3/16
.02	600	1/2	1-1/16
.05	600	9/16	1-5/16
.1	200	9/16	1-13/16
.25	200	3/4	1-7/8
.5	200	1	1-13/16

Class 21M—Both terminals insulated (with insulating tube)			
CAP. MFDS.	VOLTS D. C.	SIZE (inches) D.	L.
.05	800	11/16	1-5/8
.1	800	13/16	1-7/8
.1	600	11/16	1-3/4
.25	600	13/16	2-5/16
.25	400	13/16	2-5/16
.5	400	1-1/16	2-5/16
1.	400	1-1/16	3-15/16
1.	200	1-1/16	3-3/16
1.5	100	1-1/16	3-3/16
2.	100	1-5/16	2-11/16

Class 22M—One terminal grounded (without insulating tube)			
.0075	1000	1/2	1-1/16
.01	1000	1/2	1-1/16
.05	1000	5/8	1-13/16
.5	600	1	2
1.	600	1	3-5/8

Class 23M—One terminal grounded (with insulating tube)			
.1	1000	13/16	2-1/16
.25	1000	1-1/16	2-1/2
.5	1000	1-7/16	2-13/16
.5	800	1-1/16	3-1/16
1.	800	1-7/16	3-1/4

(Standard Capacity Tolerance on the above units is ± 20%. Closer or wider tolerances may be obtained if required.)

Standard or Special Units to Meet Every Need

FAST Capacitors are produced in many types and sizes in standard or special designs. We can supply paper capacitors—oil or wax impregnated—rectangular or tubular—in sizes from the smallest to the largest.

This line of FAST Capacitors have containers made of brass with a heavy tin dip. The terminals are made with bushings of NEOPRENE and BAKELITE and are coated with "fungus-resistant" insulating varnish. They have excellent stability over a wide range of temperatures and frequencies—will pass recognized thermal and salt water immersion tests.

Inquiries are particularly invited from organizations planning to build that *better* equipment for the new day ahead. Please feel free to call us on any capacitor problems.

"When You Think of Capacitors...Think FAST"

JOHN E. FAST & CO.

Capacitor Specialists for a Quarter-Century

3125 North Crawford Avenue, Chicago 41

Canadian Representatives: Benwire Engineering Works Reg'd. 2101 Bennett Avenue, Montreal, for Power Factor Correction
J. R. Longstaffe, Ltd., 11 King Street, W., Toronto 1, for Special Applications

NO 5 IN THE IRC NEW PRODUCT PARADE

IRC PRESENTS

THE NEW FRW
FLAT
WIRE WOUND RESISTORS

Flat as a flounder, efficient as a standard tubular wire wound . . . *and available right now for essential uses* . . . the new Type FRW packs a wealth of features to recommend it for many limited-space applications.

Five standard sizes, covering the 0.1 to 22,000 ohm range, are now being built to JAN-R-26 specifications for RW20, RW21, RW22, RW23 and RW24 requirements.

Non-magnetic mounting brackets extending through the resistor allow easy and economical mounting, aid in uniform heat distribution along the entire length of the resistor, and serve as conductors to transfer internal heat to the chassis.

FRW's may be mounted vertically or horizontally, either singly or "stacked." Although light in weight, they have exceptional mechanical strength and withstand severe vibration. They reflect in every detail IRC's traditional high quality.

For more complete details write for FRW engineering data bulletin, now in preparation.

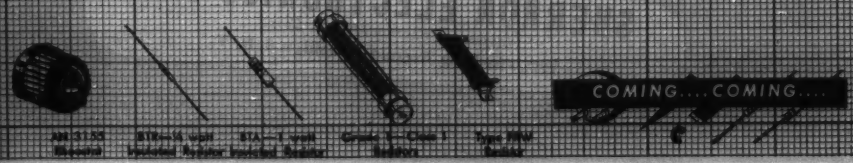
INTERNATIONAL RESISTANCE CO.

Dept. 5-C
401 NORTH BROAD STREET, PHILADELPHIA 8, PA.

IRC makes more types of resistance units, in more shapes, for more applications than any other manufacturer in the world.

DESIGNED FOR PERFORMANCE • FIXED & VARIABLE RESISTORS •

IRC



TO COAXIAL CABLE MANUFACTURERS

Check these factors with

SHERRON TEST EQUIPMENT

- ★ Corona and Dielectric Strength
- ★ Frequency Cut-off
- ★ Ultra High Frequency Loss
- ★ Insulation Resistance
- ★ Characteristic Impedance
- ★ Power Factor
- ★ Capacitance

Users of Sherron test units are equipped to find the answer to the knotty problem of reduced cable production. They rely on equipment to help achieve and maintain *quality control!* Sherron's complete laboratory facilities, practical engineering skill and years of manufacturing experience are available to coaxial cable manufacturers for design, development and production of appropriate testing equipment.

Sherron Electronics

"Where The Ideal is the Standard Snerron Test Units are Standard Equipment"

SHERRON ELECTRONICS CO.

Division of Sherron Metallic Corp.

1201 Flushing Avenue, Brooklyn 6, N. Y.

45% average
MOTOR OVERLOAD
AND No
TROUBLE FOR
4 YEARS

Powerful Electric Shovel

Rock Crushers with 100 HP Synchronous Motors

Ball Mills with 400 to 900 HP Motors

ELECTRICAL MAINTENANCE SUCCESS STORY

Motor maintenance, as we see it, means much more than simple replacement of parts which fail. It means taking into account the causes of failure and guarding against them. The result, as shown throughout the large plant in which the photos above were taken, is rotating electrical equipment better suited to its task than it was when it was originally installed. The typical National electrical maintenance success story is really one of improved performance, not merely maintenance.

Examples in this one plant: A motor, rated at 40 horsepower but carrying a 58 horsepower load (45% overload) failed time after time with ordinary windings. In 1940 National Mica-Glas coils were installed; there has been no shut-down since that time because of electrical failure.

Two generators had to be wound about twice a year. National redesigned the windings to meet the special conditions five years ago; there has been no trouble since. (See top photograph above.)

One hundred horsepower synchronous motors, with flywheels (see middle photograph above), 400, 500 and 900 horsepower motors on ball mills (see bottom photograph above) and other electric power units throughout the plant deliver better performance because of National replacement coils.

Up-to-the-minute National plants, experienced engineering and a record of accomplishment second to none are ready for any problem involving the redesign or repair of your rotating electrical machines.

NATIONAL ELECTRIC COIL COMPANY

★ COLUMBUS OHIO, U. S. A. ★

To assist the equipment designer Federal offers comprehensive data on high frequency cables.

This technical information sheet provides the design-engineer with pertinent electrical and physical characteristics...including impedance, capacitance, attenuation, diameter, materials, and weight . . . for Federal's wide variety of high-frequency cables.

Single and double braid, armored, dual conductor and dual coaxial, air-spaced, low capacitance lines, and antenna lead-in wire . . . there's a right type for your job, backed by the built-in superiority that's a tradition with Federal.

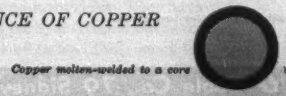
Special developments in flexible low-loss cables by Federal have resulted in superior cables for all types of transmission. For a better job, see Federal first.

Write for your cable information sheet today.

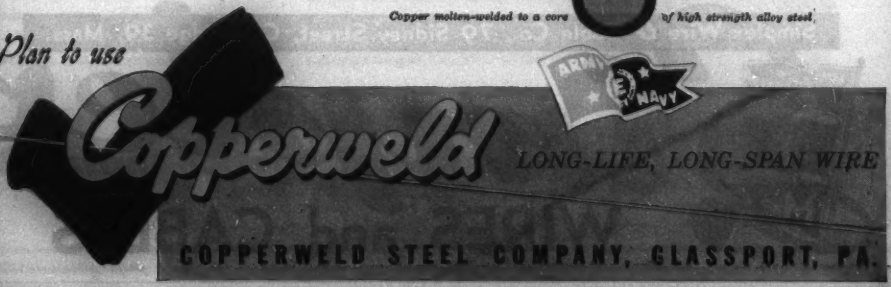
Federal Telephone and Radio Corporation

Remember: Copperweld has the best electrical conductance of any high strength conductor—is 2 to 3 times stronger than hard-drawn copper wire—and has greater tensile strength than any wire of comparable electrical properties . . .

ONLY COPPERWELD COMBINES THE HIGH STRENGTH AND RUGGEDNESS OF STEEL WITH THE CONDUCTIVITY AND PERMANENCE OF COPPER



Plan to use



SIMPLEX-ANHYDREX UNDERGROUND CABLES

NEED NO PROTECTION FROM *Moisture*

Underground cables for electrical distribution are exposed to moisture which can cause a lot of trouble and seriously interfere with service. Metallic sheaths will keep moisture out of the cables but they often create other problems of electrolysis, corrosion, sheath losses and maintenance. A flexible, non-metallic covering, such as a rubber sheath, that will not absorb water is the ideal protection.

Simplex-ANHYDREX Underground cables are now made with synthetic insulations and sheaths that are suitable for underground service in ducts or directly in the ground. Exposure to moisture, even permanent submersion in water, has no effect upon their electrical stability. For steady, uniform underground distribution Simplex-ANHYDREX Underground cables are what you need.

Our experience with low water absorption insulations over many years is at your service whenever moisture creates a cable problem for you.

Buna S has replaced natural rubber in Simplex insulations.

Simplex Wire & Cable Co., 79 Sidney Street, Cambridge 39, Mass.

Simplex

WIRES and CABLES

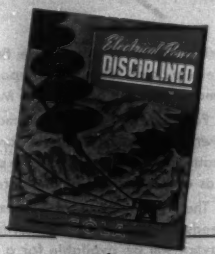
That SOLA CONSTANT VOLTAGE TRANSFORMER, built into our equipment, will eliminate a majority of our most critical field problems

Every sales manager of electrical equipment knows the number of expensive service calls, the number of complaints of sub-standard performance that can be traced directly to unstable line voltages.

A majority of them can be avoided by simply specifying "SOLA Constant Voltage Transformers" while the equipment is still on the drafting board.

The inclusion of SOLA Constant Voltage Transformers in the basic design can generally be accomplished at an actual saving in cost. Their use frequently eliminates the need for other component parts whose only function is to provide superfluous manual control over the equipment.

SOLA Constant Voltage Transformers require no supervision. They have no moving parts or delicate networks to get out of order. They react instantly and automatically to line voltage disturbances, correct fluctuations as great as 30% to the safe operating limits called for on the label. They protect both themselves and the equipment against short circuit.



To Manufacturers:
Built-in voltage control guarantees the voltage called for on your label. Consult our engineers on details of design specifications.
Ask for Bulletin ACV-102

SOLA
Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago 14, Ill.

When Laytex-insulated wire first reached New Guinea, the natives were puzzled about its purpose. So were the inhabitants of other lands—from the Solomons to Mongolia.

For Laytex has gone into many, many regions where no wire had ever gone before. Under arctic cold, steaming tropic heat, the shattering shock of heavy explosions, Laytex performs better than was ever expected of any wire.

The entire output of Laytex Wires and Cables goes to fill the needs of war. But in a not-too-distant future the advantages of Laytex will be available for a long list of important home services... Buildings, Police and Fire Alarms, Communications, Signalling, Power, Control, and many more.

Rubber Insulation at Its Best

U.S. Laytex

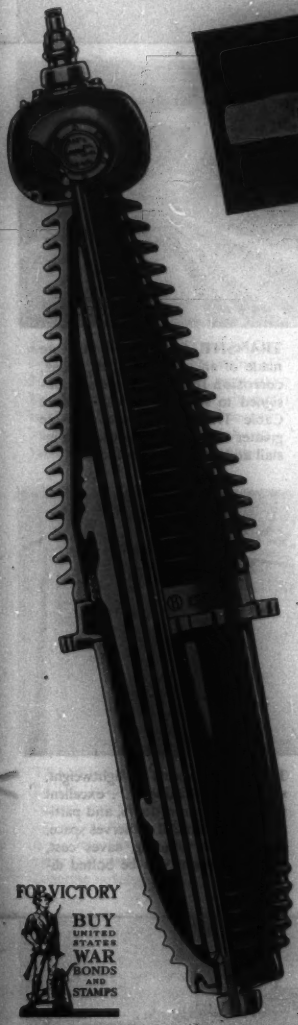
ELECTRICAL WIRES AND CABLES

Serving Through Science

UNITED STATES RUBBER COMPANY

1230 SIXTH AVENUE, ROCKEFELLER CENTER, NEW YORK 20, N. Y. • In Canada: DOMINION RUBBER CO., LTD.

ONLY PORCELAIN Can Withstand The Tests O-B Gives Your Bushing



IN BUYING a critical piece of insulation like a bushing, you have a vital interest in what the manufacturer knows about it--not what he knows about the subject in general so much as what he knows about *that bushing* in particular, from a standpoint of inspection and tests...O-B has an exclusive advantage here. Using porcelain as an internal dielectric, it can be subjected to over-voltage without harm. Each component O-B part must withstand three minutes of continuous, 60-cycle flashover before assembly. Such testing will seek out the slightest flaw. Passing such a test is a positive assurance of soundness...Every O-B bushing you get has withstood this routine proving test, whose severity would destroy a less substantial dielectric than porcelain. O-B knows a lot about *that particular bushing* you buy; we know it will duplicate the outstanding service performance of thousands of others like it. It has been tested piece by piece. That's what you buy when you specify O-B.

1904-H

FOR VICTORY BUY UNITED STATES WAR BONDS AND STAMPS

Ohio Brass

MANSFIELD, OHIO

CANADIAN OHIO BRASS COMPANY, LIMITED, NIAGARA FALLS, ONTARIO

Safeguard Future

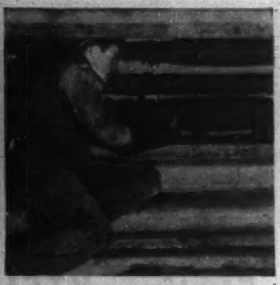
ASBESTOS EBONY is a permanent, inorganic mineral product. It won't rust, rot, shrink, crack or buckle. Impervious to water, gas, oil, and ordinary chemicals. Has high dielectric strength and insulation resistance.

TRANSITE CABLE TRAYS are made of an incombustible, strong, corrosion-resistant material. Designed to support cables, Transite Cable Trays save space, provide greater accessibility, cost less to install and need no maintenance.

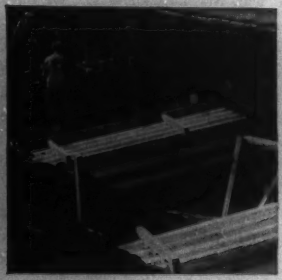
SEALING COMPOUNDS. J-M makes several—Duxseal, Pakseal, Tranolseal and Uniseal, each one with special characteristics. All are easily workable at 35° F., with no slump at 300° F. They won't harden materially when exposed to air.

TRANCELL sheets are lightweight, strong, fire-resisting . . . excellent for cell structures, doors, and partitions. J-M Trancell conserves space, reduces floor loading, saves cost, since equipment can be bolted directly to it.

Construction . . .



CABLE FIREPROOFING. Niagrite-Asbestoment, consisting of Niagrite, a commercially pure asbestos felted tape with or without reinforcement, and Asbestoment, an efficient refractory material, provides fireproof protection for cables.



TRANSITE CONDUIT and KOR-DUCT, made of asbestos fiber and cement, are fireproof, highly resistant to corrosion, electrolysis, and soil chemicals . . . are readily installed. Transite Conduit needs no concrete envelope underground.

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WHEN the green light "Go Ahead!" flashes for plant renewal and future expansion . . . *be ready to put these dependable Johns-Manville Electrical Materials to work for you.*

During the past critical years of sustained peak loads, J-M materials have helped engineers avoid waste and cut costs . . . by savings on installation expense, by reduced fuel consumption. And J-M Electrical Materials help further by providing an *extra* margin of safety!

Developed in the extensive Johns-Manville Research Laboratory, J-M-Electrical Materials are backed by the know-how acquired through 87 years of experience in solving construction problems.

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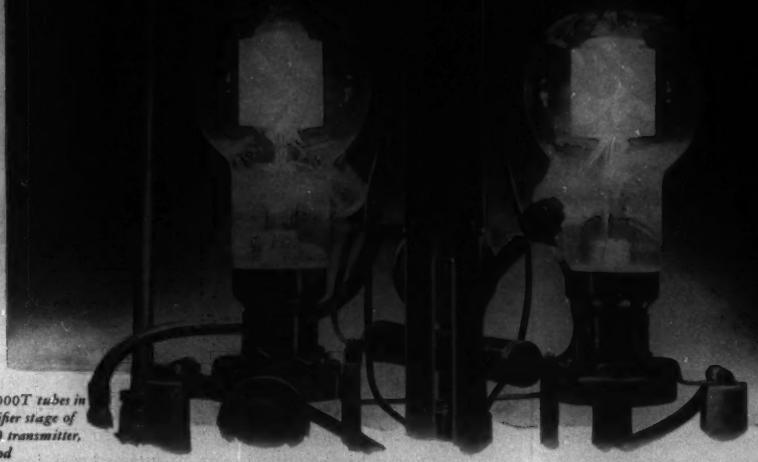

Eimac 1000T tubes in an amplifier stage of W6XAO transmitter, Hollywood

At Don Lee Hollywood... Station KTSL using EIMAC TUBES *since* 1938

Julia Lee Wright, noted Home Economics Director of "The Family Circle" magazine being interviewed, and telltale revealing tricks of her trade.

Two young comedians, Robert Sweeny and Hal March, currently on transcontinental radio show, give a preview of their talents for television broadcast over W6XAO.

Work on television station W6XAO (Commercial station KTSL) began in November 1930; and thirteen months later, Dec. 23, 1931, it was on the air on the ultra high frequencies, the first present day television to operate on schedule. Today the station occupies elaborate copper sheathed studios which stand 1700 feet above Hollywood with an antenna on a 300-foot tower.

The program log shows almost every type of presentation. Highest in interest and achievement are the remote pick-ups and special event broadcasts made simultaneously or recorded on film for release later. Studio presentations, especially those directed to war activities, have become a duration standard.

Under the direction of Harry R. Lubcke, television station KTSL will be in daily schedule immediately after the war. Mr. Lubcke says: "We have been using Eimac tubes in our television transmitter since about 1938... We have found them good and reliable performers... their design is such that a favorable ratio of power output to tube and circuit capacitance is obtained... we look forward to using new Eimac tubes which may be forthcoming."

Here again is a statement from a leader in the field, which offers clear evidence that Eimac tubes are first choice of leading electronic engineers throughout the world.

Write for your copy of Electronic Telesis—a 64 page booklet fully illustrated—covering the fundamentals of Electronics and many of its important applications. In layman's language.

Follow the leaders to

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TUBES

EITEL-McCULLOUGH, Inc. 991 San Mateo Avenue, San Bruno, Calif.
Plants located at: San Bruno, California and Salt Lake City, Utah
Export Agents: Frazar & Hansen, 301 Clay St., San Francisco 11, Calif., U. S. A.

it's attention to [illegible] details . . .

Human skill can't be scientifically tested. That's why it is always the unknown quantity in manufacturing. But experience is a reliable guide to measuring the true value of skill. In building C-D Capacitors precision work is backed by the accumulated experience of conscientious men and women, some of whom have been with Cornell-Dubilier for nearly the whole of our 34 years of existence; others for five, ten and twenty years of loyal service.

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ALSO AT NEW BEDFORD, BROOKLINE, WORCESTER, MASS., PROVIDENCE, R. I.

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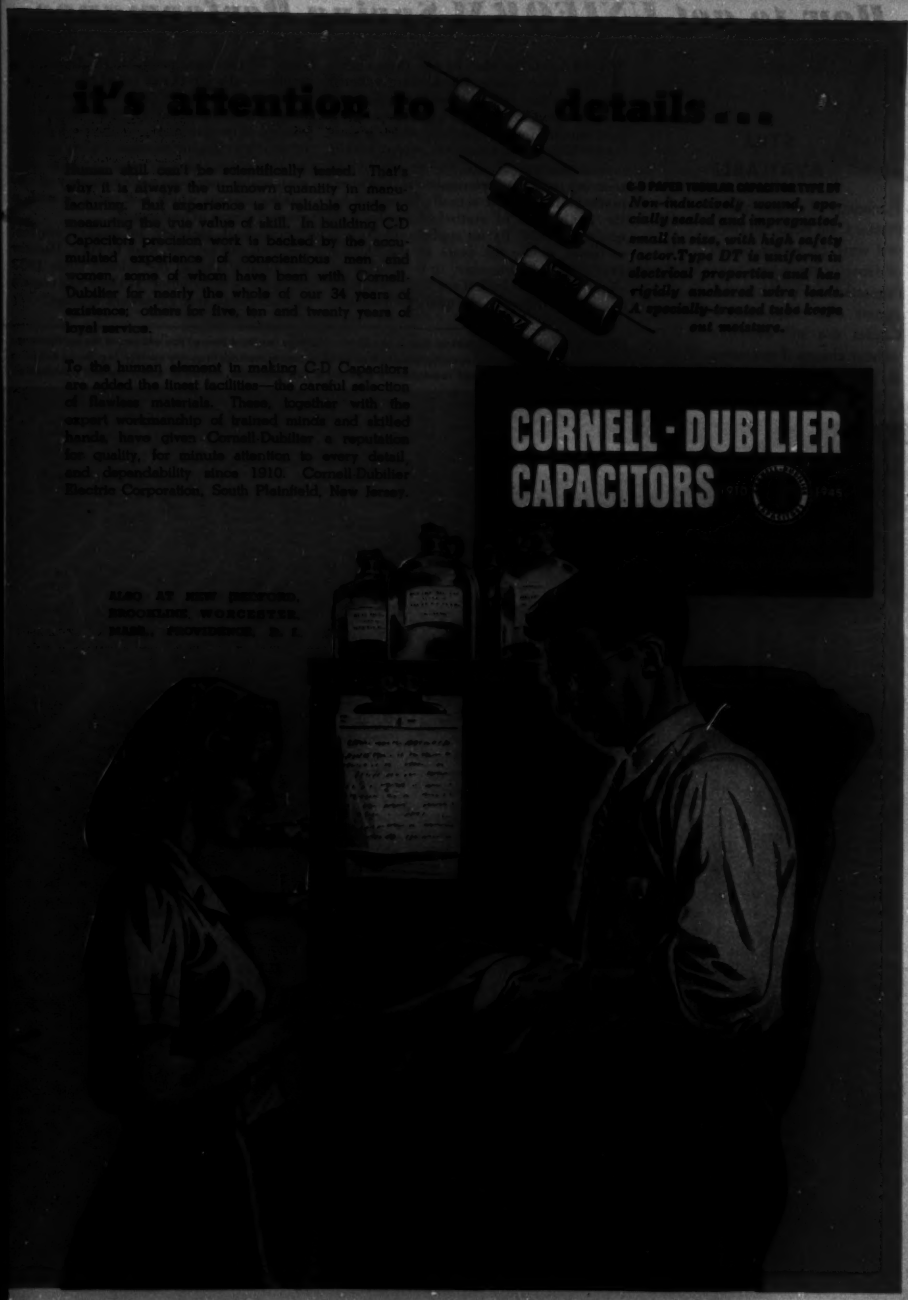
Non-inductively wound, specially sealed and impregnated, small in size, with high safety factor. Type DT is uniform in electrical properties and has rigidly anchored wire leads. A specially-treated tube keeps out moisture.

CORNELL - DUBILIER CAPACITORS



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STILL AVAILABLE

Thousands of copies of the Hunter Data Book, an original work on spring design and specifications, have been requested by product designers and manufacturers. Copies are still available without charge if requested on your letterhead.

IT IS A safe bet that no two things have ever been made which were exactly alike. How then is it possible to obtain from two, two hundred, or two million springs a performance in your product which is uniform? Well, it isn't possible except within certain tolerance limits. The probability of securing uniform performance is, however, mathematically and actually increased by the application of statistical methods in quality control. By an application of such methods, in use for years at the Hunter Pressed Steel Company, it is possible to check and control all of the various factors which may influence the quality characteristics of the final product, to detect the tendency of a job to run out of control, and to make immediately the adjustments necessary to keep it in control. Statistical control of quality increases the probability of securing a greater number of okay springs in any given quantity and therefore immeasurably increases your certainty of obtaining springs which will perform with a greater degree of uniformity.

Statistical methods in quality control are, you can be sure, here to stay. Hunter has been a user of the science since 1932 as well as a contributor. Is there any reason any longer to buy guesswork springs?

CONTROLLED SPRINGS—*The chances that in any batch of springs (as those below) you will secure the performance you require, are greatly increased by the application of statistical methods in quality control. In order to establish quality control, Hunter devised revolutionary methods of fast inspection, details of which are still confidential.*

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FOR BETTER PERFORMANCE

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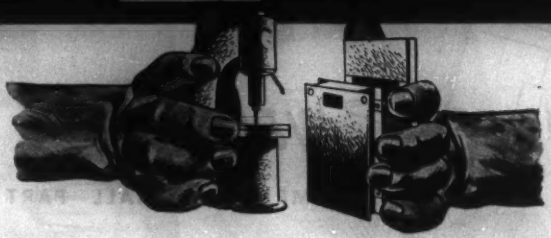

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Class B insulation which permits higher temperature rise may be specified to meet location or load conditions.

WRITE FOR BULLETIN No. 1116-A which describes AmerTran general purpose dry type transformers, gives construction data, electrical ratings, prices, etc.

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SIMPLIFIES SMALL PART ASSEMBLY

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Available for either wall or bench-mounting, the one-shot operations of the Westinghouse SP-18 require no sequence timer. You can learn more about this improved electronic welder control from your nearest Westinghouse office. Or write Westinghouse Electric & Manufacturing Company, P. O. Box 868, Pittsburgh 30, Pa.

J-21319

The improved, simplified Westinghouse SP-18 welder control measures only 14½" x 20" x 12½". Note complete accessibility of interior of the unit by simply unlocking hinged panel. The control Thyratron is shown on the front of the swinging panel while the air-cooled Ignitron is mounted directly behind it.

Westinghouse

Electronics at Work

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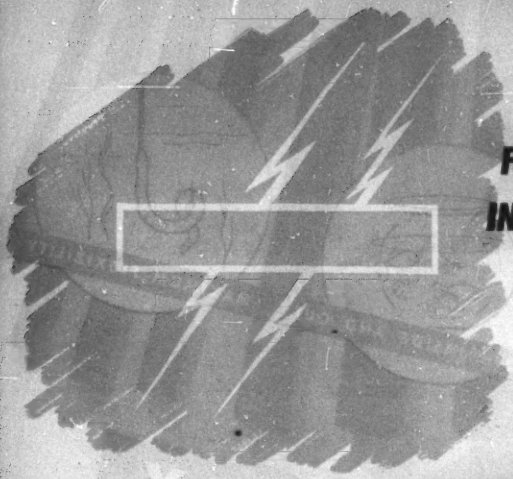

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Polythene was originated by Imperial Chemical Industries, Ltd., in Great Britain, and has been developed and improved by Du Pont.

AVAILABILITY. Du Pont is now producing polythene for important war purposes. However, quantities up to twenty-five pounds can be secured for experimental purposes according to WPB Order M-300, Schedule 60. Write for properties chart and other data to E. I. du Pont de Nemours & Co. (Inc.), Plastics Dept., Arlington, N. J.

DU PONT

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...THROUGH CHEMISTRY

For Plastics—consult **DU PONT**

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Silver-Copper-Graphite

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Silver-Molybdenum

Silver-Tungsten

Silver-Nickel-Molybdenum

Silver-Nickel-Tungsten

and dozens of special alloys.

One-third smaller by volume and with half as many parts! That, in brief, is the story of a circuit breaker produced by a leading manufacturer, and made possible by use of silver-tungsten contacts utilizing the recently developed Stackpole "FW 41" formula.

Thanks to the efficiency of this new contact material, the interrupting capacity of the circuit breaker in *its new small size* has actually been increased from 10,000 amperes to 15,000 amperes. On special test, it has interrupted 21,000 amperes without apparent damage!

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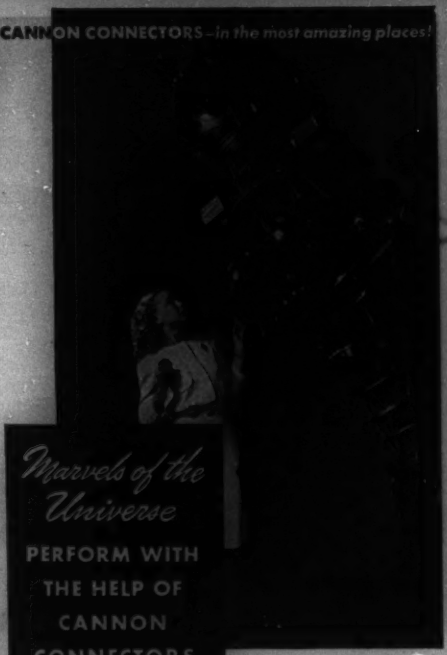

Marvels of the Universe PERFORM WITH THE HELP OF CANNON CONNECTORS

At the world-famous Griffith Observatory the scientific exhibits—working models of Nature's wonders—operate electrically and electronically through circuits connected by Cannon Connectors.

Such is their dependability that G. W. Bunton, chief technician of the observatory states: *"Since their installation in 1935, no Cannon Connector has been responsible for a circuit failure."*

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Should have general experience in Electrical or Radio Measurements. Graduate engineer (radio or electrical) from recognized engineering school, desirable. Long-established radio-electrical components manufacturer in New England, doing war work at present. Postwar future for right man. Give detailed outline of experience, etc., salary requirements. Address Box 353, Electrical Engineering, 33 West 39th St., New York 18, N.Y.

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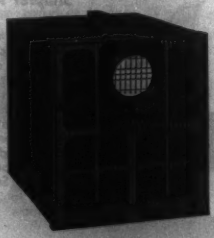

Oscillograph

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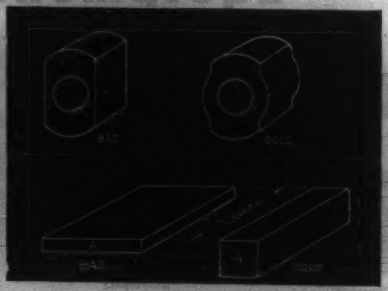

That skinny chap at the left could do with some setting up exercises. An extended course at some accredited physical culture school would put some flesh on his bones, where it belongs. And as for that rather portly gentlemen on the right, he's no Superman. He's too fat.

Magnets, like people, should be well proportioned. Just the right amounts of metal at the right places give them the mechanical strength to withstand the necessary grinding down and subsequent annealing operations. The shape as well as size has a bearing on the energy content desired. A few simple rules on proper proportioning which will help in designing magnets are discussed in our pamphlet "PERMANENT MAGNET DESIGN." We'll be glad to send you a copy.

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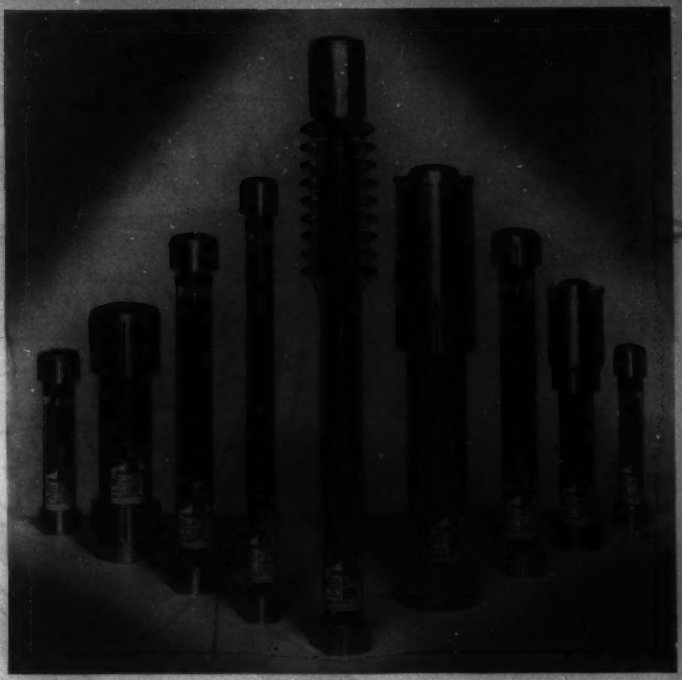

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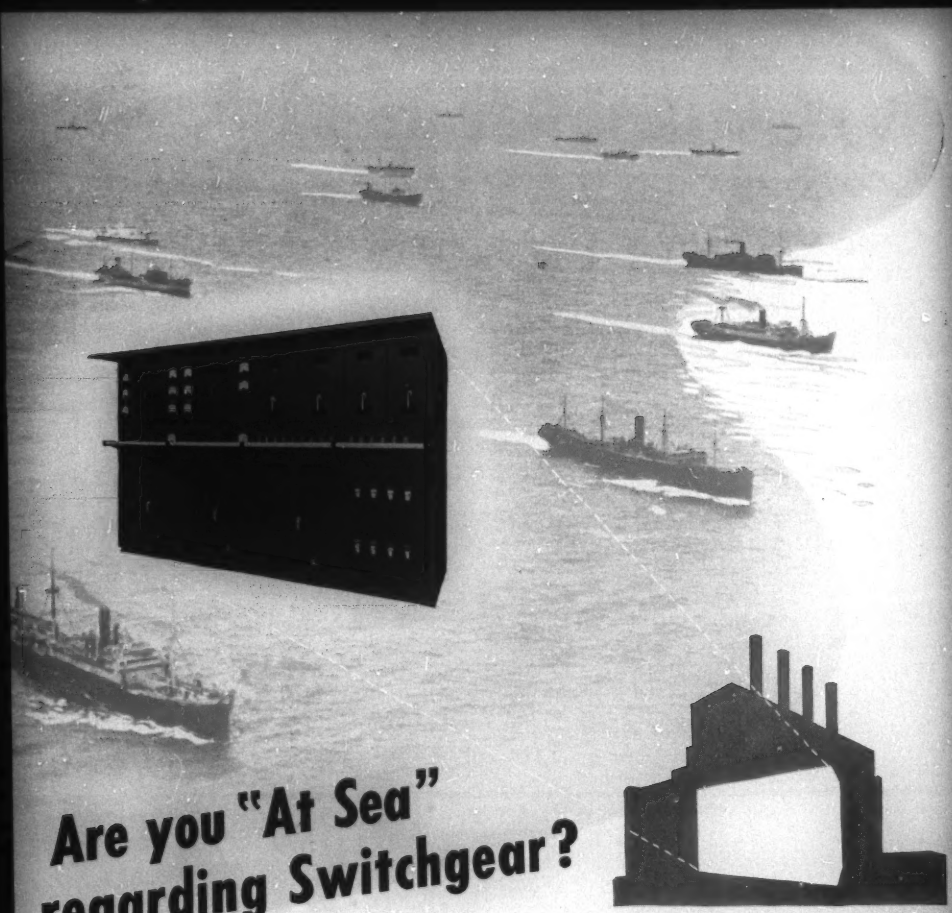

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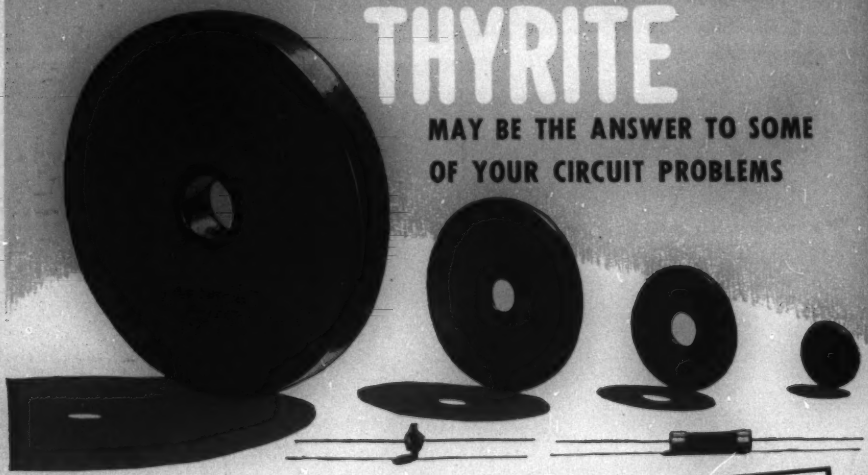

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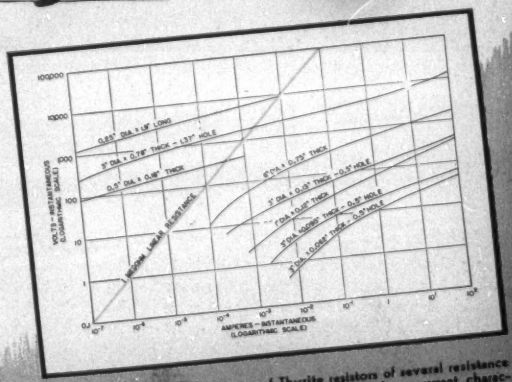

Typical volt-ampere characteristics of Thyrite resistors of several resistance levels and power ratings. Note that the nonlinear voltage-current characteristic extends over an extremely wide current range. Compare it with the characteristic (orange line) of a 1-megohm linear resistor.

Here are some of its
MANY APPLICATIONS

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